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Preface

Taihu Lake basin is located in the core area of the Yangtze River Delta; the total area of the basin is 36.9 thousand km^2 of which the water area of Taihu is 2338 km^2, covering Jiangsu, Zhejiang, and Anhui provinces and Shanghai city. Owing to favorable climate and natural conditions, this region was developed very early and is playing an important role in socioeconomic development of China. In 2005, the GDP (gross domestic product) of the basin area accounted for about 11.7 % of the whole country.

With a rapid development of economy and society in Taihu Lake basin, the water consumption and wastewater discharge are increasing, and the water quality of the basin is declining since past 30 years. During 2005, the water quality of the lake basin along the watershed of 2700 km long was studied and found that for over 89 % of the basin, the annual water quality deterioration was of class III standard, and 61 % was worse than the class V standard. The average water quality comprehensive evaluation of Taihu Lake was for the inferior class V (including TP (total phosphorus), TN (total nitrogen) index), whereas the NH_3^--N index was for the class II, TP was for class IV, TN index was inferior to the class V, and COD_{MN} (chemical oxygen demand) was for class III.

Among various factors of water pollution and eutrophication in Taihu Lake basin, the contribution of non-point source pollution is crucial. The statistics of the Taihu basin showed that the contribution of non-point source pollution to the drainage was around 347,000 tons of COD and 2.5 million tons of NH_3-N. According to an estimate of the former State Environmental Protection Administration, the water pollutants in the country from the industries, human living, and agricultural non-point source pollution were approximately 1/3 each. Of the pollution load in Taihu Lake, 83 % of TN and 84 % of TP were from farmlands, rural livestock and poultry breeding industry, urban and rural combination areas, and rural life. The contribution of non-point source pollution was far more than point source from industries and urban life. In the plain area of Taihu Lake basin, addition of COD to the rivers was 346.9 thousand tons per year with the largest proportion from rural human living, accounting for 41.6 % of the total COD in the river, followed by aquaculture production, accounting for 27.2 % of the total COD. The addition of TP to the rivers was 6.7 thousand tons per year with the largest proportion from rural life, accounting for 50.6 % of the total TP, followed by farmland runoff pollution, accounting for 26.9 %. The addition of TN to the rivers was 64.8 thousand tons per year with the biggest share from rural human living, accounting for 32.8 % of the total, followed by livestock and poultry breeding, accounting for 23.9 %. In specific, addition of NH_3-N to the rivers was 25.1 thousand tons per year with the largest proportion from rural life, accounting for 60.2 % of the total, followed by farmland runoff pollution, which accounted for 26.7 % of the total. Thus, there are various sources for pollution of rivers and lakes, i.e., TN and NH_3-N are the largest pollutants in rural areas, rural life, and farmland runoff, while TP is more in rural life and livestock and poultry farming. Thereby, it is not difficult to understand why in 2007 blue-green algae broke out in Taihu Lake.

In order to overcome the serious non-point source pollution in Taihu Lake watershed, the following measures are generally taken: (1) **Ecological ridge technology**: Runoff is an important way of nutrient loss. The current farmland ridge is only about 20 cm high in the farming area of Taihu Lake basin which can produce surface runoff easily at the time of higher rainfall. It is estimated that by heightening the existing ridge by 10–15 cm, the runoff from 30 to 50 mm rainfall can be effectively prevented and can reduce most of the farmland runoff. At the same time, some plants can be planted on both sides of the ridge to form a buffer zone, which can effectively check surface runoff and thereby reduce nutrient losses through runoff water. (2) **Ecological ditch technology:** Currently, most of the ditches are with hard cement surface which results in the discharge of surface runoff directly into rivers causing eutrophication of water. Therefore, it is wise to change the existing channels to hardened eco-channels by hard boards with holes which make the crops or grasses to grow and absorb nutrients from the leaching water. By this way, the loss of farmland nutrients can be effectively intercepted. At the same time, certain plants can be planted at the center of the ditches, which can reduce the velocity of water flow, increase the retention time, improve crop nutrition, and also improve self-purification capacity of water bodies. (3) **Ecological wetland treatment technology:** Through the construction of ecological ditches and ecological interception system, most of the nutrients lost from farmlands can be intercepted, but still some nutrients go into the river. Man can take advantage of the existing ecological wetlands or artificial floating islands by planting emergent plants, leaf floating plants, etc., to fully absorb and utilize these nutrients. The hydraulic plants having some economic value can be selected to ensure certain economic benefits to local farmers besides improving water quality.

Forestry measures play a certain role in controlling non-point source pollution and protecting water security. In order to understand the role of forestry measures on water quality improvement, some projects have been undertaken since 2008 which are supported by State Ministry of Science and Technology and Department of Science and Technology of Jiangsu Province. This book has been written based on the research findings of the projects.

This book mainly focuses on ecological approaches of preventing and controlling non-point source (NPS) pollution based on forestry measures. Firstly, the characteristics of NPS pollution in Taihu Lake watershed and water eutrophication evaluation methods are described. Then, the role of relevant forestry measures in combating water pollution such as public welfare forest development, urban forestry development, techniques of hedgerows planting in slope lands, shelter belt establishment, N and P absorption by willows, hydrophyte selection, and land use pattern optimization is presented. Correspondingly, quantified data on the effect of forestry measures on soil properties, plant species diversity and source reduction and sink increase of NPS pollution are given in this book. Moreover, for the first time, the landscape change and its effect on water quality in Taihu Lake are discussed, in addition to purification of eutrophicated water and dynamic kinetics of nitrogen absorption by trees. Finally, the techniques of development of riparian forest buffers and ponds–wetlands integrated management system are indicated and described.

This book is useful for researchers, lecturers, professionals, and administrators working on water environment and ecological development as well as graduate students, senior undergraduates, and persons interested in water security.

Hongzhou, China Jianfeng Zhang
April 2016

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Contents

Chapter 1
Characteristics of Non-point Source (NPS) Pollution in Taihu Lake Watershed

Abstract Taihu Lake is located at the center of Changjiang delta region. The Lake and its effluent rivers are important water sources for about 40 million inhabitants and rapidly increasing industrial factories in Shanghai, Jiangsu, and Zhejiang. The pollutants originate mainly from acidy rain, home sewage of the vast number of inhabitants, livestock manure, agricultural fertilizers, and pesticides applied over fields in the drainage basin, and the industrial sewage. Some research studies have indicated that industrial sewage, domestic wastewater, and agricultural non-point source (NPS) pollutants accounted for 16, 25, and 59 % of total nitrogen for water eutrophication, respectively, and for 10, 60, and 30 % of total phosphorous, respectively, in Taihu Lake. Due to pollutants, the Lake water is getting highly eutrophic, with frequent blooms of blue-green algae. Compared with point source pollutants, diffuse pollution is much complicated and difficult to control. It is clear that NPS pollution in Taihu Lake region has been quite serious and has become the main threat for water environment health. Thus, combating NPS pollution must be paid great attention.

Keywords Non-point source pollution · Source–sink · Taihu Lake · Blue-green algae bloom · Eutrophication

The Taihu Lake basin has an area of 36,500 km^2, located in three provinces and one municipality. The percentage area in Jiangsu, Zhejiang, Anhui provinces, and Shanghai is 52, 33.4, 13.5, and 0.1 %, respectively. The water area in the lake basin accounts for 17.5 % of the entire lake area (Qin 1999). The Lake has the multi-function of flood water storage, irrigation, navigation, water supply, aquaculture, and tourism. It is the main drinking water source for 40 million residents in areas such as Wuxi and Suzhou and neighboring Shanghai and Zhejiang. The Lake is also famous for its abundant production of fishes and crabs and skillfully managed aquaculture farms on the coast (Chai et al. 2006).

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1.1 Introduction

The region along Taihu basin is developed very earlier owing to the favorable natural conditions (see Table 1.1), which is called "Kingdom of fishing and farming." The vegetation resources are also abundant there. Important types of forest (main species of trees) are pine forest (*Pinus massoniana*), bamboo forest (*Phyllostachys pubescens*), and mixed evergreen-deciduous scrub. Important herbaceous vegetations are swampy grassland of reeds and other emerged water plants on the lake shore and along water courses. The major crops grown are rice (single or double cropping), wheat, rapeseed, tea, mulberry, and fruit trees [peach, orange, loquat, myrica, plum, Japanese apricot (*Prunus mume*), and jujube] (Zhang et al. 2007) (see Figs. 1.1, 1.2, and 1.3).

In addition to supporting heavy boat traffic, Taihu Lake provides some of the best known water-side scenery in China for domestic and foreign sightseeing visitors. Hence, the urbanization level of the lake basin ranks the first in the entire country.

Table 1.1 Natural condition in Taihu Lake basin

Longitude: E 116°28′–123°
Latitude: N 23°33′–32°08’
Elevation (meters above sea level): 3.1–4.5 m
Rainfall:
Mean annual rainfall (mm): 974 mm
Month of highest rainfall: June 156 mm
Month of lowest rainfall: January 38 mm
Other notes on rainfall (fog, snow, and/or other forms of precipitation): sometimes storm in summer
Temperature:
Mean annual temperature: 15.6 °C
Month of highest temperature: July 29.9 °C
Month of lowest temperature: January 2.9 °C
Other notes on temperature: hot summer (June, July, and August)
Soil:
Depth to parent material: 1–5 m
pH: 6.2–8.0
Color: brown
Texture: sand loam
Geological origin: sedimentation by flooding
Other notes on soil: paddy soil in some parts
Exposure to sunlight: 2000 h annually
Terrain:
Slope steepness (% or degrees): plain area, 0–5°
Drainage: not so heavy
Depth of water table: 0.5–3 m

Fig. 1.1 Forests grow around Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 1.2 Forests grow in hills (Photograph taken by Jianfeng Zhang)

Fig. 1.3 Agricultural production around Taihu Lake (Photograph taken by Jianfeng Zhang)

Table 1.2 Water quality state in Taihu (August 17–23, 2008)

Location	Profile	pH	DO[a] (mg/l)	COD (mg/l)	NH_3–N (mg/l)	Water quality grading
Shazhu, Wuxi	Lake body	8.14	6.46	2.80	0.28	II
Lanshanzui, Yixing	Lake body	8.23	6.52	3.70	0.30	II
Xishan, Suzhou	Lake body	7.44	4.69	4.90	0.23	IV

[a]DO means dissolved oxygen

However, due to the excess consumption of resources for the regional socioeconomic development, forest coverage reduced from 17 % in 1950s to 13 % in 1980s, wetland area reduced more than 40 % with land transition, on an average decreased 1469 ha (hectare) annually during 1950–1985. With forest felling and soil erosion, the farm ecosystem was damaged, wetland reduced, buffer zone disappeared, and pollutants moved into rivers and lakes directly. Consequently, the eco-environment has been drastically deteriorated. In the period of 1981–2000, TP increased by 25.0 % annually in the Lake, while TN by 11.7 % and COD by 4–6 %. From 1980s, the water quality of Taihu Lake has been reduced by one grade in every 10 years, and now, it has become a typical area which lacks quality water (Zhang 2004). The water quality state of Taihu Lake as per Chinese General Station of Water Environmental Monitoring is shown in Table 1.2.

Although the government gave importance to the water pollution treatment and took several measures, mainly focusing on point source pollution such as industrial wastewater decontamination and lake water cleaning, the water quality of Taihu Lake is still exasperate and the status of water pollution is austere. The affair of blue-green algae bloom occurred in May 2007 alarmed the people and the government and made to recognize the risk and hazards of eutrophication. Therefore, much more attention needs to be given. No doubt, the function of forests is significant in controlling agricultural non-point source (NPS) pollution in Taihu Lake basin.

1.2 Analysis on Source and Sink of Agricultural Non-point Pollution

1.2.1 Framework of Source and Sink of NPS Pollution

For Taihu Lake basin, the inflowing water comes mainly from mountains to the west and southwest of the Lake, while the draining rivers start mostly from the east coast of the Lake. Several rivers and channels connect the lake with Changjiang, but the water flux is controlled by dams to maintain the Lake water level fluctuation within a range of 2–3 m (Qin 1999).

According to the source–sink theory, the source means inputs of pollutants, and sink indicates outputs of pollutants. In this basin, source–sink of agricultural non-point pollution could be described as in Fig. 1.4. It can be inferred from Fig. 1.4 that the causes of water body pollution and eutrophication are complicated and multiple.

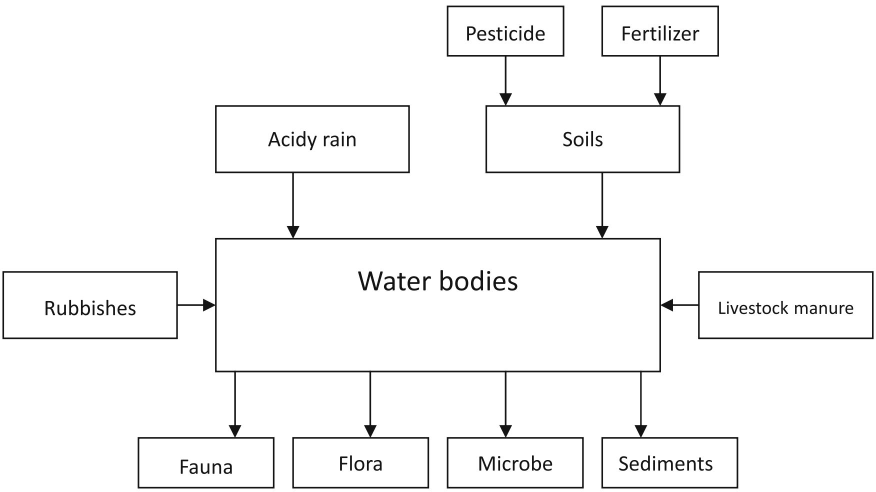

Fig. 1.4 Source–sink of agricultural non-point pollution in Taihu Lake basin

1.2.2 Components of the Source

According to the framework of source–sink of NPS pollution as shown in Fig. 1.4, the major agricultural NPS pollution is the result of acidy rain, livestock manure, fertilizers and pesticides, and rubbishes and garbage. Of these sources, acidy rain occurred naturally, while the others are concerned with human activities (see Figs. 1.5 and 1.6).

Located upstream of the Lake basin, Xitiaoxi River and Dongtiaoxi River both lied in Zhejiang province are recognized as the headwaters of the Lake. In the region, local people live on the mountain range, planting bamboo and/or tea trees, cultivating grain, or cash crops. During these farming activities, agrochemicals were applied, usually at higher dose to get good harvest and income. During heavy rains or storms, water and soil erosion will occur and the soil nutrients moved into the Lake through runoff water (Zhang et al. 2007).

With rapid development of industry and excess consumption of pesticides for agriculture, large amount of pollutants and nutrients such as nitrogen and phosphorus are drained into surrounding channels and finally into the Lake resulting in overgrowth of algae and deterioration of water quality including oxygen depletion leading to severe pollution.

Fig. 1.5 Pollution from industrial production (Photograph taken by Jianfeng Zhang)

Fig. 1.6 Pollution from livestock and poultry breeding (Photograph taken by Jianfeng Zhang)

1.2.3 Distribution of the Sink

Figure 1.4 shows that the nutrients leading to eutrophication could be taken up and/or digested by aquatic animals such as plankton, fishes, shrimps, aquatic plants, or riparian forests which are naturally grown or planted. Nowadays, some fries such as grass carp and chub are often released to rivers, lakes, and reservoirs to purify water. On the other hand, around the watershed, usually wetlands are established comprising aquatic plants such as duck weeds, butter cup, and water lily and are harvested annually to reduce nutrient content in water bodies. Sometimes, certain woody species are chosen and planted such as *Nyssa aquatica*, *Liquidambar styraciflua*, *Quercus nuttallii*, *Carya illinoinensis* Koch, and *Phyllostachys nigra*.

Meanwhile, the microbes played an important role to consume nutrients and prevent algae from blooming (Daniel et al. 1998). Some compounds and elements, especially heavy metals, sunk into river bed or lake bottom and became sediments.

1.3 Formation of Non-point Source Pollution

1.3.1 Rainfall

Direct driving force of NPS pollution is surface runoff oriented from rainfall so that temporal distribution of the rainfall determines temporal characteristics of NPS pollution. Normally there are 3 rainy seasons throughout the year in Taihu Lake region, namely spring season during April and May, plum season during June and July, and typhoon season during August and September. Ma's research (1997) concluded that the load of agricultural NPS pollution increased with increase in annual precipitation. Taking Suzhou River region NPS pollution as an example, the load quantity in different rainy reasons showed that plum reason > autumn season > spring season > winter season (Wang et al. 2002). Hence, the local farmers should choose rational fertilizing time in order to avoid the loss of N and P.

1.3.2 Human Activity

Natural and human activities are the important causes leading to NPS pollution, produce various pollutants, and resulted in different spatial distributions of NPS pollution. The research by Yu et al. (2003) observed that water quality of Xitiaoxi River region in western Zhejiang Province worsened gradually from upstream to the downstream. The important reason for water quality deterioration in the region was NPS pollution, which was mainly originated from fertilizer loss from farmlands and bamboo forests, surface runoff of cities and towns, and domestic sewages. Research on agricultural NPS pollution in Hangzhou–Jiaxing–Huzhou Plain indicated that the load contribution rates of livestock manure, domestic sewage, and surface runoff to water pollution were 43.81, 29.91, and 22.43 %, respectively (Qian et al. 2002) (see Figs. 1.7, 1.8 and 1.9). The load of NPS pollution in Shanghai suburbs was sizeable, and the COD, TN, and TP drained into water environment were 16.73×10^4 t, 2.54×10^4 t, and 0.473×10^4 t, respectively, which had substantial impact on the water quality of Shanghai suburbs (Zhang et al. 1997). Moreover, the farmlands were in intensive management in Taihu Lake region of southern Jiangsu Province, and more N and P fertilizers were applied (345 and 18 kg ha^{-1} a^{-1}, respectively); and the load quantity of N and P reached 3.37×10^4 t and 440.4 t, respectively in 1987 (Ma et al. 1997). The research which analyzed various types of N non-point source pollution in Xueyan town of first-class nature reserves of Taihu Lake indicated that sources of diffuse N pollution including farmlands, rural residential areas, urban residential areas, and livestock accounted for 72.7, 18.9, 7.2, and 1.2 % (Guo et al. 2003). This showed that N loss from farmlands was the main diffuse pollution source. Besides, the agricultural NPS pollution of Yili River region in western Taihu Lake was increasingly serious owing to the same reason (Xu et al. 2001). The average output of TN in the farmland in Hufu, Yixing city was 4.643 kg ha^{-1} a^{-1} (Jiao et al. 2003).

Fig. 1.7 Pollution from domestic sewages (Photograph taken by Jianfeng Zhang)

Fig. 1.8 Pollution from damaged fields (Photograph taken by Jianfeng Zhang)

Fig. 1.9 Pollution from surface runoff (Photograph taken by Jianfeng Zhang)

1.4 Management and Prevention of NPS Pollution

Management and control from NPS pollution could be started with controlling the pollution source and transmission pathways of pollutants, and enhancing scientific study on its formation mechanism and migration law of pollutants.

1.4.1 Key Measures on NPS Pollution Control

For different types of NPS pollution, we should take appropriate control measures. Obviously, the NPS pollution from farmlands is one of the most crucial pollution sources in Taihu Lake region. Hence, rational tillage pattern and irrigation method not only should be adopted to prevent NPS pollution, but also the management for chemical fertilizer and pesticides be strengthened. Meanwhile, in order to prevent the agricultural diffuse pollution from the source and to develop ecological agriculture, the government should encourage and guide farmers to apply chemical fertilizer and pesticide scientifically, advocate soil analysis before fertilizing to enable farmers to apply optimum fertilizer considering economic and ecological effects. On the other hand, keeping the city clean, reducing the pollution and reinforcing the garbage collection and treatment in the city can prevent the diffuse pollution of urban areas from the source.

1.4.2 Reduction on Pollutants Diffusion

Some measures should be adopted to strengthen controlling diffusion pathways of pollutants and reducing pollutant quantity draining into underground or surface water. It is reported that different plants have varied pollutants absorbing capabilities (Chen et al. 2002). Based on the principle combining with the process of landscape construction, some vegetation buffers could be built to intercept and filter diffuse pollutants (see Figs. 1.10 and 1.11). So in some places, we can create artificial gulley, wetlands (Jiang and Gui 2002), sand filter, and vegetation buffers to decrease the diffuse pollution from the farmlands surface and underground water. For the city and towns, the most effective way to fight against diffuse pollution is to accelerate the construction of pipelines of sewage collection and improve domestic sewage treatment.

Fig. 1.10 Vegetation buffers to intercept surface runoff (Photograph taken by Jianfeng Zhang)

Fig. 1.11 Vegetation buffers to protect riverbanks in Yixing (Photograph taken by Jianfeng Zhang)

1.4.3 Strengthening of Pollution Monitoring

The formation mechanism and migration law of NPS pollution have not been clarified at present. This has brought difficulties to control and manage the NPS pollution, and therefore, relevant research should be strengthened. At the same time, according to the law and regulations, different departments and different levels of the governments should set up relevant organizations to monitor and manage regularly the NPS pollution. These organizations are responsible for and approaching the origin, characteristics, and change of NPS pollution. The data of pollution monitoring are helpful for controlling and managing NPS pollution based on the study on the formation characteristics and the migration mechanism of pollutants.

References

Chai SW, Pei XM, Zhang YL et al (2006) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conserv 20(6):191–194

Chen JL, Shi LL, Zhang AG (2002) Controlling effects of forest belts on non-point source pollution of agricultural lands in Taihu Lake area, China. J Forest Res 13(3):213–216

Daniel TC, Sharpley AN, Lemunyou JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Environ Qual 27(1):251–257

Guo HY, Wang XR, Zhu JG et al (2003) Quantity of nitrogen from non-point source pollution in Taihu Lake catchment. J Agro Environ Sci 22(2):150–153

Jiang GL, Gui GB (2002) Effective of wetlands in removed of non-point pollutants from agricultural source. Agro Environ Prot 21(5):471–473, 476

Jiao F, Qin BQ, Huang WY (2003) Management of water environment in small watershed with Hufu town of Yixing city as example. China Environ Sci 23(2):220–224

Ma LS, Wang ZQ, Zhang SM et al (1997) Pollution from agricultural non-point sources and its control in river system of Taihu Lake, Jiangsu. Acta Sci Circumstantiae 17(1):39–47

Qian XH, Xu JM, Si JC et al (2002) Comprehensive survey and evaluation of agricultural nonpoint source pollution in Hang-Jia-Hu water-net plain. J Zhejiang Univ 28(2):147–150

Qin BQ (1999) Hydrodynamics on Lake Taihu, China. Ambio 26(8):45–48

Wang SP, Yu LZ, Xu SY et al (2002) Research of Non-point sources pollution loading in Suzhou Creek. Res Environ Sci 15(6):20–23, 27

Xu PZ, Qin BQ, Huang WY et al (2001) Assessment of water quality and nutrition to water bodies the Yilihe Watershed, Taihu Basin. J Lake Sci 13(4):315–321

Yu XX, Yang GS, Ou WX (2003) Impacts of non-point source pollution on the water environment of Xitiaoxi Watershed, upper Taihu Basin. J Lake Sci 15(1):49–55

Zhang JF (2004) Agroforestry and its application in amelioration of saline soils in eastern China coastal region. Forest Stud China 6(2):27–33

Zhang DD, Zhang JQ, Wang YG (1997) The main non-point source pollution in Shanghai suburbs and harness countermeasure. Shanghai Environ Sci 16(3):1–3

Zhang JF, Fang MY, Li S (2007) Developing agroforestry in slopelands to combat non-point pollution in China. Chin Forest Sci Technol 6(4):67–72

Chapter 2
Evaluation of Water Eutrophication on Taihu Lake-Connected Channels in Yixing City

Abstract Taihu Lake is one of the five largest freshwater lakes in China. The gross economy of the basin has an important contribution to the whole country. Meanwhile, it is the main source of drinking water for 40 million residents of the region. Hence, it is significant to take up research on water pollution prevention. In order to approach deeply the countermeasures for controlling eutrophication of the lake, 10 channels connected to Taihu Lake in Yixing were chosen to test the degree of eutrophication based on the Carlson trophic state index (TSI). By employing techniques to measure chlorophyll "a" and other chemical indicators such as nitrogen and phosphorus in water body of the channels, TSI was computed using formula, TSI = 10 (2.46 + ln Chla/ln 2.5). The results indicated that TSI, between 53.77 and 70.03, and chlorophyll "a" were suitable parameters to indicate the degree of eutrophication, as well as the content of TP. Through the measurement and evaluation, it was found that all the 10 channels were eutrophic, and the major cause was possibly the higher quantity of P in the channels. The location and land use type of these channels indicated that eutrophication, although a natural process over time, was often accelerated by human activities. Human beings influence the lake by increasing the concentration of plant nutrients, primarily phosphorous. These nutrients can enter the waterway through agricultural land, sewage, or wastewater and cause over enrichment.

Keywords Carlson trophic state index · Eutrophication · Taihu Lake · Chlorophyll · Evaluation · Lake-connected channel

Taihu Lake is one of the five largest freshwater lakes in China. The gross economy of the lake basin has significant contribution to the national economy. It is located at 119°31′–120°03′E and 31°07′–31°7′N and covers 2300 km^2, vastly situated/falling in Jiangsu Province (see Fig. 2.1). It is the main source of drinking water for 40 million residents of surrounding area and neighboring Shanghai and Zhejiang (Qin 2009). However, due to excess consumption of resources for the regional economic development, the eco-environment has been drastically deteriorated. From 80s in the last century, the water quality of Taihu Lake has descended one grade in every 10 year, and now, it has become a typical area of lacking quality water (Zhang et al. 2009). Although the government has given importance/attention

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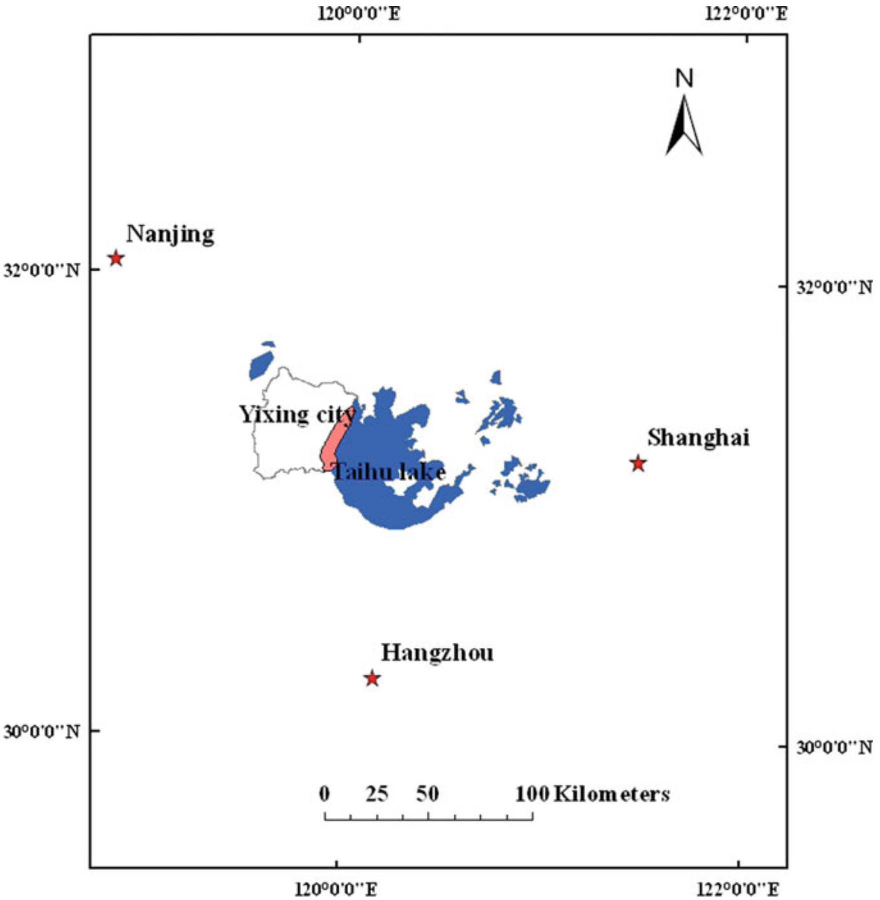


Fig. 2.1 Location of Taihu

to control the water pollution and taken many measures, mainly focusing on the point source pollution such as industrial wastewater decontamination and lake water cleaning, the water quality of Taihu Lake is still exasperate and the situation of water pollution is austere. The affair of blue-green algae bloom occurred in May 2007 alarmed the people and the government to realize the risk and hazards of eutrophication (Zhang et al. 2010; Zhu et al. 2008).

2.1 Introduction

The causes of water body pollution and eutrophication problem are complicated and multiple (Daniel et al. 1998; Heiskary 1985). With the rapid development of industry and the excess consumption of pesticide for agriculture, large amount of pollutants and nutrients such as nitrogen and phosphorus were drained into the lake and surrounding channels. These materials cause an overgrowth of algae and further deterioration of water environment, including oxygen depletion, which resulted in severe eutrophication (Chai et al. 2006a, b; Hu et al. 2010; Kennedy 2001; Zhang et al. 2007a, b).

Totally, 43 km of Taihu Lake water body is located in Yixing city, Jiangsu Province and now there are mainly 14 Taihu Lake-connected channels, whose water quality is rather different (see Figs. 2.2 and 2.3). It is obvious that the trophic state of these channels will have a certain effect on water quality of Taihu Lake (Qin 2009). Up to now this field has not been touched.

Hence, it is necessary and significant to evaluate the trophic state of these channels for water pollution treatment in the basin.

The trophic state is defined as the total weight of biomass in a given water body at the time of measurement. Various methods have been adopted for the classification of lakes and to indicate their trophic status (Chai et al. 2006a, b; Harper 1992). The most commonly and widely used method is based on productivity, while the frequently used biomass-related trophic state index (TSI) is that of Carlson (1977). This index requires a minimum data and is generally easy to

Fig. 2.2 One of the Taihu Lake-connected channels in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 2.3 Another channel connected with Taihu Lake in Yixing (Photograph taken by Jianfeng Zhang)

understand, but the traditional nutrient-related trophic state categories are ideal for use in volunteer programmes.

Carlson's index uses a log transformation of Secchi disk values as a measure of algal biomass on a scale from 0 to 110. Each increase of ten units on the scale represents doubling of algal biomass. Because chlorophyll "a" and total phosphorus are usually closely correlated with Secchi disk measurements, these parameters can also be assigned TSI values (Carlson 1980). The Carlson TSI is useful for comparing lakes within a region and for assessing changes in trophic status over time. Ranges of TSI values are often grouped into trophic state classifications. The range between 40 and 50 is usually associated with mesotrophy (moderate productivity). Index values greater than 50 are associated with eutrophy (high productivity). Values less than 40 are associated with oligotrophy (low productivity).

In this test, 10 channels were chosen in Yixing to analyze their trophic state based on Carlson TSI. Here the method of Secchi disk was not employed instead of chlorophyll determination considering the available experimental conditions. Moreover, land use system along these channels was investigated, in order to analyze and find the influencing factors on the trophic state for specific channel.

2.2 Materials and Methods

2.2.1 Study Area Description

The selected 10 channels connected with Taihu Lake were located in Yixing (see Fig. 2.4). Water samples were started collecting in the beginning of August 2010 and continued through September and October in the year (see Figs. 2.5, 2.6 and 2.7).

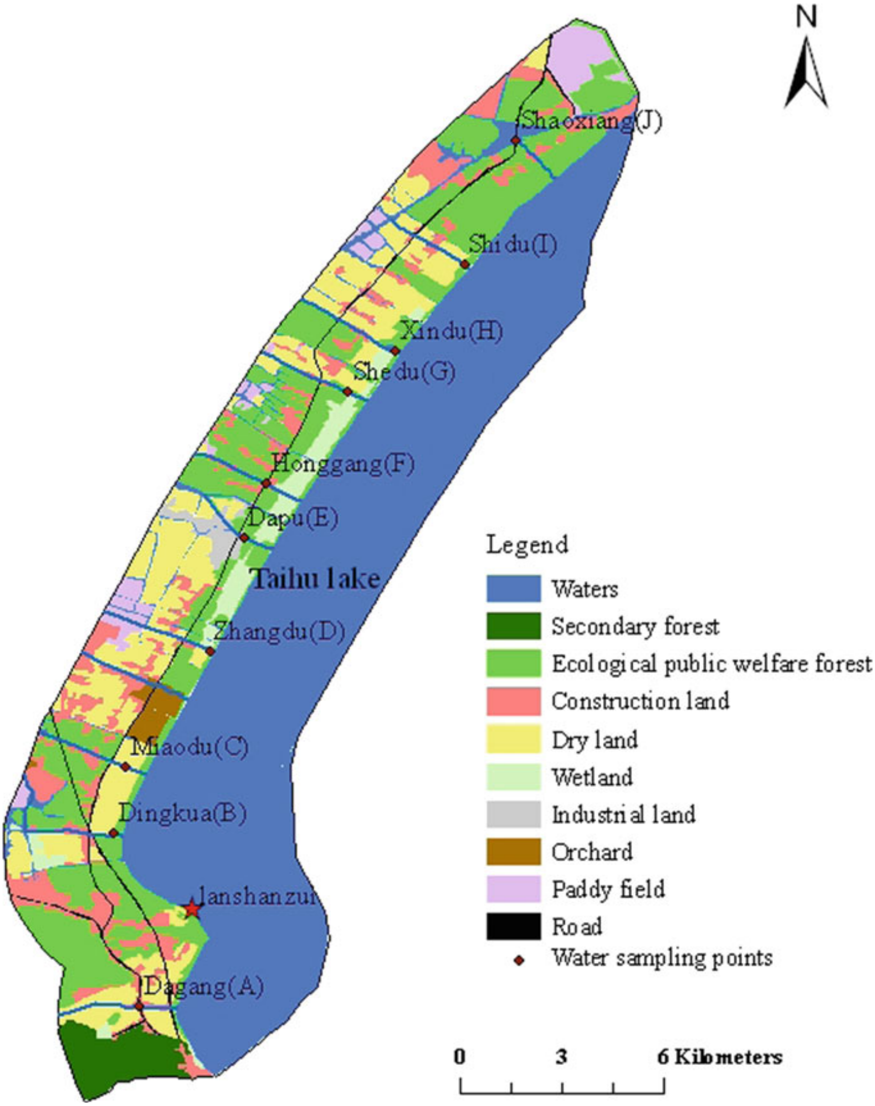


Fig. 2.4 Sampling sites at Taihu Lake-connected channels in Yixing

Fig. 2.5 One of the sampling channels in Yixing (Photograph taken by Ying Wang)

Fig. 2.6 One of the water quality monitor points in Yixing (Photograph taken by Ying Wang)

Fig. 2.7 Water samples collect in Yixing (Photograph taken by Ying Wang)

During the process, the global positioning system (GPS) was used to find the location of the 10 sampling sites. All of these 10 sites were located in the lacustrine zone. Their features are shown in Table 2.1.

2.2.2 *Determination of Parameters*

For each channel, water samples were taken by using an Alpha style horizontal sampler starting 1 m below the surface and continuing at 2 m intervals to the channel bottom. Approximately, 500 ml of water was collected at each sampling depth. At each site, water samples were mixed and brought to laboratory for analysis. A 250 ml portion of each water sample was filtered through a glass fiber filter, and the filter was frozen for chlorophyll analysis. The filters were ground with a tissue grinder in a solution of aqueous acetone, poured into conical tubes, and centrifuged at 500xG for 25 min. The supernatant was analyzed for chlorophyll “a” (Chla). Then, Chla concentration was measured by reading absorbance at 665 nm and 750 nm using a spectrophotometer (Unico UV-2000, Shanghai, China). A 100 ml portion of each sample was acidified to pH 2 with 6 N HCl and frozen for total nutrient determinations. A 25 ml portion of each acidified and unfiltered water sample was digested for total Kjeldahl N (TKN) and TP by using H_2SO_4 with mercuric sulfate as a catalyst. Total nitrogen (TN) was measured by the alkaline

Table 2.1 Sites description for sampling plots

Sampling sites	Latitude N	Longitude E	Above sea level (m)	Site description
Dagangkou (A1)	31.1897	119.8974	11	Village, commune habitat
A2	31.1897	119.8981	8	Entrance to the lake
A3	31.1894	119.9055	9	Entrance to the lake
Dingkuagang (B1)	31.2354	119.8901	5	Fallow land
B2	31.2354	119.8905	4	Abandoned land
B3	31.2349	119.8925	2	Abandoned land
Miaodugang (C1)	31.2613	119.8937	13	Garden
C2	31.2608	119.8954	10	Garden
C3	31.2746	119.9019	8	Garden
Zhangdugang (D1)	31.2823	119.9066	23	Forested land
D2	31.2824	119.9065	0	Wetland
D3	31.2840	119.9161	1	Wetland
Dapugang (E1)	31.2838	119.9160	1	Farmland
E2	31.2881	119.9213	3	Farmland
E3	31.3048	119.9264	4	Fallow land
Honggangdong (F1)	31.3279	119.9309	5	Watercourse
F3	31.3277	119.9316	4	Industrial zone
F3	31.3280	119.9315	4	Entrance
Shedugang (G1)	31.3335	119.9456	5	Poplar plantation
G2	31.3342	119.9431	5	Poplar plantation
G3	31.3373	119.9366	1	Bridge
Xindugang (H1)	31.3683	119.9558	3	Wetland
H2	31.3632	119.9652	6	Wetland
H3	31.3626	119.9658	3	Wetland; entrance
Shidugang (I1)	31.3855	119.9844	4	Entrance to the lake
I2	31.3862	119.9835	4	Entrance to the lake
I3	31.3870	119.9826	7	Entrance to the lake
Shaoxinggang (J1)	31.4190	119.9972	6	Poplar plantation
J2	31.4253	120.0125	2	Paddy field
J3	31.4236	120.0098	2	Paddy field

potassium persulfate digestion-UV spectrophotometric method. TP was analyzed by the ammonium molybdate method. All the above methods were described in detail by Huang (1999).

Data analysis was done based on SPSS version16.

2.2.3 Computation Carlson Trophic State Index

Considering the actual state of Taihu Lake, the formula to calculate Carlson TSI was modified as (Zhang and Li 2007):

$$\mathrm{TSI} = 10(2.46 + \ln \mathrm{Chla} / \ln 2.5)$$

where, TSI = Carlson TSI, ln = natural logarithm.

2.3 Results

2.3.1 TN, TP, and Chlorophyll a (Chla)

TN, TP and Chla in waters collected from different channels were analyzed and the results were shown in Figs. 2.8, 2.9 and 2.10.

All the three parameters are closely concerned with water trophic state. In general, bigger the quantity, higher is the trophic state, although the relation varies among the state and the indicator. However, for each channel, the values of parameters changed greatly. For example, TN for channel A was the highest, while for channel A, TP, and Chla were not so high.

According to the results depicted in Fig. 2.8, the highest value of TN was 4.32 mg L^{-1} in channel A, while the lowest value of TN was 1.98 mg L^{-1} in channel C. It is well known that TN is one of the crucial factors leading to eutrophication. For channel A, around the sampling site there are local people living and water samples were collected from the entrance of the channel. Usually, local residents throw garbage everywhere and living rubbishes are discharged into the

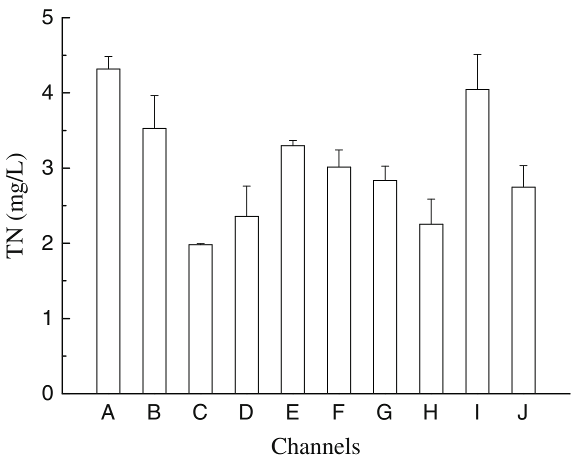


Fig. 2.8 Values of TN in different channels

Fig. 2.9 Values of TP in different channels

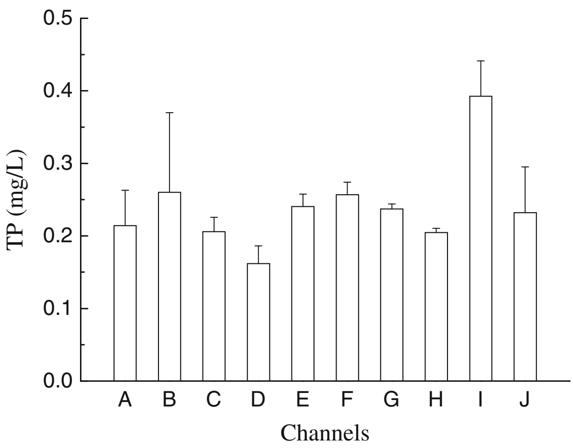
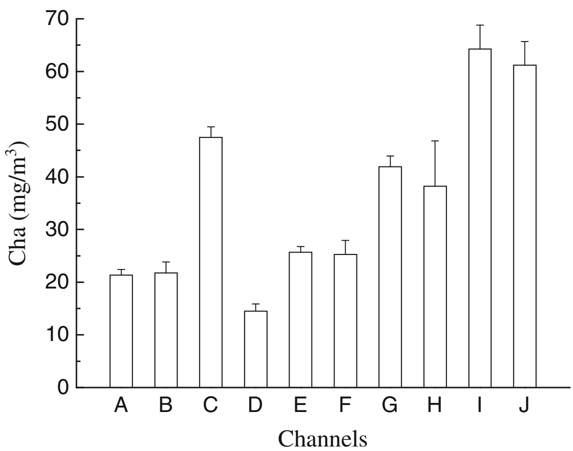


Fig. 2.10 Values of Chla in different channels



channel. Hence, it is understood that the highest value of TN occurred here. On the other hand, for channel C, the land use type is garden under the conditions of little chemical fertilizer application. Furthermore, the altitude of the sampling site is little high, which means that there are few sediments.

The highest TP value of 0.39 mg L^{-1} was recorded in channel I, while the lowest value of 0.16 mg L^{-1} was recoded in channel D (Fig. 2.9). It is clear that mostly P comes from soils due to soil erosion goes to channels. As given in Table 2.1, the sample site of channel I is at the entrance and the upper reaches of the channel are farm land which implies that more fertilizers and pesticides were applied. So sediments gradually increase at the entrance. In channel D, the land use patterns are forest land and wetland, soil and water erosion is prevented to a greater extent, moreover, part of P is taken up by aquatic plants in wetland.

In Fig. 2.10, it can be seen that the highest value of Chla is 64.26 mg M^{-3} was recoded in channel I, while the lowest value of 14.48 mg M^{-3} was in channel D. Obviously, the result is similar with TP. Previous research has also demonstrated strong relationship between P and Chla in lakes (Heiskary 1985).

2.3.2 Carlson Trophic State Index

Values of Chla from specific channels were put into the formula: TSI = 10 (2.46 + ln Chla/ln 2.5) and the results are presented in Table 2.2.

The data in Table 2.2 showed that the values of TSI were different for each channel. The highest is 70.03 for channel I, while the lowest is 53.77 for channel D. No doubt the result is similar to TP and Chla (Dillon and Rigler 1974).

A lake is usually classified as being in one of three possible classes: oligotrophic, mesotrophic, or eutrophic. Lakes with extreme trophic indices may also be considered hyperoligotrophic or hypereutrophic. Table 2.3 demonstrates how the index values translated into trophic classes (Carlson 1980; James et al. 2009).

According to data in Table 2.3, these channels fell into Eutrophic state in view of TSI, although there was more or less a little difference among the channels. Oligotrophic lakes generally host very little or no aquatic vegetation and are relatively clear, while eutrophic lakes tend to host large quantities of organisms, including algal blooms. Each trophic class supports different types of fish and other organisms, as well. If the algal biomass in a lake or other water body reaches too high a concentration (say <80 TSI), massive fish die-off may occur as decomposing biomass deoxygenates the water.

The data in Table 2.3 showed that, when TSI is 50–70, TP is 24–96 (μg L^{-1}). However, the Fig. 2.8, indicated that the content of TP is too high, which means that the main cause of eutrophication is TP for these channels in Yixing.

Phosphorus is often regarded as the main culprit in cases of eutrophication in lakes subjected to point source pollution from sewage. The concentration of algae and the trophic state of lakes correspond well to phosphorus levels in water

Table 2.2 Values of TSI for target channels

Channels	TSI(Chla)
Dagangkou (A)	57.98
Dingkuagang (B)	58.20
Miaodugang (C)	66.72
Zhangdugang (D)	53.77
Dapugang (E)	60.02
Honggangdong (F)	59.83
Shedugang (G)	65.36
Xindugang (H)	64.36
Shidugang (I)	70.03
Shaoxianggang (J)	69.49

Table 2.3 Trophic classification based on TSI, Chla, TN, and TP

TSI	Chla/(mg m^{-3})	TP/(μg L^{-1})	TN/(mg L^{-1})	Trophic class
<30–40	0–2.6	0–12	0.05–0.16	Oligotrophic
40–50	2.6–20	12–24	0.16–0.31	Mesotrophic
50–70	20–56	24–96	0.31–1.20	Eutrophic
70–100+	56–155+	96–384+	1.20–9.10+	Hypereutrophic

(Dong et al. 2008; Smith 1982). Studies conducted in the experimental Lake Area in Ontario have shown a relationship between the addition of phosphorus and the rate of eutrophication. Humankind has increased the rate of phosphorus cycling on earth by four times, mainly due to agricultural fertilizer production and application (APIS 2005). The controls of point sources of phosphorus have resulted in rapid control of eutrophication, mainly due to land use changes (Zhang et al. 2008).

2.4 Discussion

The results indicated that all the 10 Taihu Lake-connected channels are eutrophic based on the values of TSI. It is understood that around these channels are farmlands, e.g., paddy and garden of cash trees and vegetables, in addition to villages and industrial zone (Table 2.1). In this case, non-point source pollution is getting serious. Of the causes of eutrophication for these channels land use system is crucial and vital.

In order to promote plant growth and to increase agricultural production, local people often apply many nitrogenous and phosphate fertilizers. This encourage/facilitate run-off when rainfall or irrigation occurs. The way of N, P outflow includes: (1) enters the ground water along with the surface runoff; (2) forms the subsurface current (in soil), carrying on the transversal motion through the soil, then goes into the ground water body; (3) infiltrates through the soil to the ground water. The first 2 ways are primary cause leading to water eutrophication (Horne and Goldman 1994). Recent research indicated that the phosphorus can be dissolved or absorbed in soil particles and move through soil subsurface current, then enter the river, the lake or the bay. But for nitrogen, its seepage ability is strong, can infiltrate and pollute the ground water (James et al. 2005). For nitrogen and phosphorus, during the process of adsorption and desorption in soil, some part dissolves in the water, another part with the soil particle deposition, becomes bottom sediments in the lake or the river.

In addition, excessive application of domestic animal excrement in farmland also will cause the nutrients outflow along with the surface runoff, thus pollute the water body.

Human activities also can accelerate the rate at which nutrients enter ecosystems. Runoff from agriculture, pollution from septic, sewers, and other human-related activities increase the flux of both inorganic nutrients and organic substances into terrestrial and aquatic ecosystems (Harper 1992).

However, it must be pointed out that during the period of sample collection, the rainfall is lower than in normal years. Moreover, these channels are small, i.e., the volume of water flow is low. Thus, the content of TN and TP is getting high (Allan and Castillo 2007).

2.5 Conclusions

The techniques to measure Chlorophyll "a" and other chemical indicators such as nitrogen and phosphorus in water bodies of the Taihu Lake-connected channels were employed. The results showed that Chlorophyll "a" is one of the suitable parameters to indicate the degree of eutrophication based on Carlson TSI, and it is closely related to the content of TP. Through the measurement and evaluation, it is found that all the 10 channels are eutrophic. The major cause of eutrophication is possibly due to higher P content in waters. Based on the location and land use type of these channels, it can be inferred that although eutrophication is a natural process over time, it is often accelerated by human activities termed as cultural eutrophication. Humans influence the lake by increasing the concentration of plant nutrients, primarily phosphorous. These nutrients can enter the waterway through agricultural land, sewage, or wastewater which can cause over enrichment.

References

Allan JD, Castillo MM (2007) Stream ecology: structure and function of running waters. Springer, The Netherlands 436

APIS (2005) Website: Air pollution Information System Eutrophication

Carlson RE (1977) A trophic state index for lakes. Limnol Oceanogr 22(2):361–369

Carlson RE (1980) More complication in the Chlorophyll a-Secchi disc relationship. Limnol Oceanogr 25:378–382

Chai C, Yu ZM, Song XX (2006a) The status and characteristics of eutrophication in the Yangtze River (Changjiang) estuary and the adjacent East China Sea, China. Hydrobiologia 563 (1):313–328

Chai SW, Pei XM, Zhang YL et al (2006b) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conserv 20(6):191–194

Daniel TC, Sharpley AN, Lemunyou JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Environ Qual 27(1):251–257

Dillon PJ, Rigler FH (1974) The phosphorus-chlorophyll relationship in lakes. Limnol Oceanogr 19(5):767–773

Dong XH, Bennion H, Yang XD (2008) Tracking eutrophication in Taihu Lake using the diatom record: potential and problem. J Paleolimnol 40:413–429

Harper D (1992) Eutrophication of freshwaters. Chapman and Hall, London

Heiskary SA (1985) Trophic status of Minnesota lakes. MPCA, Roseville

Horne AJ, Goldman CR (1994) Limnology, 2nd edn. McGraw-Hill, New York

Hu CH, Zhou WB, Wang ML et al (2010) Inorganic nitrogen and phosphate and potential eutrophication assessment in Lake Poyang. J Lake Sci 22(5):723–728

Huang XF (1999) Survey, observation and analysis of lake ecology. Standards Press of China, Beijing 247

James C, Fisher J, Russell V (2005) Nitrate availability and hydrophyte species richness in shallow lakes. Freshw Biol 50(6):1049–1063

James RT, Havens K, Zhu GW (2009) Comparative analysis of nutrients, chlorophyll and transparency in two large shallow lakes (Lake Taihu, P. R. China and Lake Okeechobee, USA). Hydrobiologia 627:211–231

Kennedy RH (2001) Considerations for establishing nutrient criteria for reservoirs. Lake Reservoir Manage 17(3):175–187

Qin B (2009) Progress and prospect on the eco-environmental research of Taihu Lake. J Lake Sci 21(4):445–455

Qin BQ, Liu ZW, Havens K (2007) Eutrophication of shallow lakes with special reference to Lake Taihu, China. Hydrobiologia 581:1–3l1

Smith VH (1982) The nitrogen and phosphorus dependence of algal biomass in lakes: an empirical and theoretical analysis. Limnol Oceanogr 27(6):1101–1112

Zhang J, Li ZH (2007) Monitoring and analysis of Zhangduhu's eutrophication. Environ Pollut Control 3:1–5

Zhang JF, Fang MY, Li S et al (2007a) Developing agroforestry in slopelands to combat non-point pollution in China. Chin Forest Sci Technol 6(4):67–72

Zhang YL, Qin BQ, Liu ML (2007b) Temporal-spatial variations of chlorophyll a and primary production in Meiliang Bay, Lake Taihu, China from 1995 to 2003. J Plankton Res 29: 709–719

Zhang JF, Shan QH, Qian HT (2008) Effects and planting techniques of hedgerow intercropping on sloping lands in agricultural non-point source pollution control. Bull Soil Water Conserv 28 (5):180–185

Zhang JF, Jiang JM, Zhang ZJ (2009) Discussion on role of forest to control agricultural non-point source pollution in Taihu lake basin-based on source-sink analysis. J Water Resour Prot 1 (5):345–350

Zhang JF, Jiang JM, Shan QH (2010) Countermeasures to control agricultural non-point source pollution in headwaters of Taihu Lake Basin. In: Management and service science (MASS 2010) international conference proceedings. (ISBN: 978-1-4244-5326-9; IEEE Catalog Number: CFP1041H-CDR)

Zhu G, Wang E, Gao G (2008) Variability of phosphorus concentration in large, shallow and eutrophic Lake Taihu, China. Water Environ Res 80(9):832–839

Chapter 3
Different Land Use Patterns to Combat NPS Pollution in the Region

Abstract Land use refers to the long-term or periodic management and renovation of land based on its natural characteristics when human have demand for it. The connotation of land use also expanded with the development of society and technology. The functions of land use have changed from single production and living to production, living, ecology, entertainment etc., and the aims of land use have developed from simple economy and society to economy, society, and ecology. The land use patterns also have changed from simplexes and independence to complexity and integration. From the ecological perspective, the optimized land use pattern can coordinate the relationship between environmental factors, reasonable exploitation of the ecological niche, and maintain the dynamic balance of ecological system through adapting the local conditions and minimizing the land weaknesses. In order to approach the optimum land use types for controlling non-point source (NPS) pollution, different land use systems were probed and practiced in Taihu Lake watershed region.

Keywords Land use pattern · Non-point source pollution · Ecological control · Agricultural production · Landscape · Forest

The land use can reflect the level of society and technology from a social viewpoint (Yu et al. 2002). And it can also reflect the interaction between environmental factors and organisms, and the flow and configuration of matter and energy from an ecological perspective (Zhang and Qin 2007). With the development of social economy and increasing of population, the land use of China arose more problems in recent years, for example, that the urbanization and industrialization took up the agricultural arable lands and caused the productive land resources reducing greatly, and agricultural extensive management model wasted a lot of land resources and seriously polluted environment (Zhang et al. 2004). With this background, optimization of land use has become a common concern of official departments and scientific institutions, as well as researchers and staff working for land resources planning and management. The optimized land use pattern should be decided based on assessment of land use efficiency (Zhang et al. 2007; Lenat and Crawford 1994). Generally, the

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ultimate goals are to achieve the collaborative optimization of quantity structure, spatial arrangement, benefits of land use, and sustained production. In view of this, selecting a land use pattern which is characterized with high producing efficiency, economic inputs, feasible farming system, social acceptable land ownership, and ecological friendly management is significant to prevent and control non-point source (NPS) pollution in Taihu Lake basin (Young 1989).

In China, land use patterns are divided into 12 first-level categories, and 56 s-level categories according to the "Land Use Conditions Classification" which is a national standard. The 12 first-level categories include arable; orchard; forest; grass; land for business and service; land for industry, land for mining and storage; land for residents; land for public management and service; specific use land; land for roads and transportation; land for water and water conservancy facilities; and the other lands.

The area of eastern Yixing is flat and distributed criss-crossing water networks. It is the catchment area of west Taihu Lake and is always famous for production area of economic crops such as fruits, vegetables, flowers. So it is clear that in this area agriculture is main land use pattern. However in recent years, some lands also were used as industrial park and residential houseyard. Agricultural land is primarily used for growing rice and vegetable and partly used to breed aquatic products. The original land use patterns cannot meet social development and environmental protection, so it is necessary to exploit new, efficient, and optimized land use patterns. From the social perspective, the optimized land use pattern can achieve the rational allocation of arable, orchard, forest, grasses, and so on, which is conducive to improve the benefits of economy, ecology, and society, coordinate the relationship between environment and human, and promote the sustainable development (Kleijn and Verbeek 2000). From the ecological perspective, the optimized land use pattern can coordinate the relationship between environmental factors, reasonable exploitation of the ecological niche, and maintain the dynamic balance of ecological system through adapting the local conditions and minimizing the land weaknesses (Archer and Marks 1997). This chapter discussed several optimized land use patterns, which are suited to combat NPS pollution in the area of Taihu Lake.

3.1 Ecological Protection Model

Ecological protection model aims to improve the ecological benefits and ensure the regional ecological security (Lee et al. 2009; Zhang et al. 1997; Yang et al. 2003). It is the primary optimization model of land use pattern in the area, including ecological protective forests and wetland parks.

3.1.1 Ecological Protective Forest Model

The test area was located in the catchment area of west bank of Taihu Lake. This area collects a large quantity of the upstream water with heavy pollution; moreover, farming system and breeding industry were also extensive. These have severely polluted the water in this district. So the primary optimization model of land use pattern in this area is ecological protective forest model. Its aim is to form a network of regional ecological protective forest based on the forest patches, such as embankment defense forest, farmland protection forest, village protection forest, and so forth (see Figs. 3.1 and 3.2). The tree species selection for these protective forests is principally based on the capacity of waterlogging resistance, and the taller arbor trees are the better. Usually, the structure of the forest is the trees combined with shrubs and grasses.

The ecological protective forest model requires a certain scale, and in general as a rule, the spacing is about 30 m width and 500 m length of the forest shelter belt in order to perform the ecological functions of forest. The optional tree species of the ecological protective forest include *Populus* spp., *Metasequoia glyptostroboides, Taxodium hybrid, Taxodium ascendens, Betula davurica, Bischofia polycarpa, Camptotheca acuminate, Quercus nuttallii, Catalpa bungei, liquidambar styraciflua, Nyss sylvatica, aquatica, Pterocarya stenoptera, Salix babylonica, Sophora japonica, Platanus, Morus alba, Paulownia elongate, Koelreuteria paniculata, Malus hupehensis, Melia azedarace, Cedrus deodara, Cinnamomum camphora, Dendrobenthamia hongkongensis, Diospyros kaki, Elaeocarpus decipiens, Fraxinus pennsylvanica, Glyptostrobus pensilis, Ilex hirsute, Viburnum tinus, Jasminum mesnyi, Distylium buxifolium, Hibiscus'Duede Brabaul, Nerium*

Fig. 3.1 Forests for embankment defense (Photograph taken by Jianfeng Zhang)

Fig. 3.2 Forests for farmland protection (Photograph taken by Jianfeng Zhang)

indicum, Ligustrum sinense, Rubus corchorifolius, Salix integra, and so on. But it is better to choose wild herbaceous plants in this forest system to reduce costs. This forest needs weeding, land cover, and replanting in the first two years after afforestation (Zhang and Sun 2005). But it should be enclosed and human interference reduced after the trees are planted.

3.1.2 Wetland Park Model

This area can exploit the ecology-friendly wetland park based on the natural advantages of higher soil moisture and groundwater level. The wetland park makes full use of the rich water network resources and various plants to resist waterlogging. The model aims at building a community structure with well-proportioned distribution, abundant species, and harmonious coexistence, through altering topography, building "sink" landscapes to absorb pollutants by surface runoff (Gao 1999; Yu et al. 2002). Mostly when constructing the wetland park based on the topography of sites, plant aquatic plants in watered-out area, and plant shrubs and trees resisting waterlogging on the bank of the Lake (see Figs. 3.3 and 3.4). Here, most of the

Fig. 3.3 Wetland park integrated with Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 3.4 Wetland park for landscape and tourism (Photograph taken by Jianfeng Zhang)

aquatic plants or hydrophytes belong to the herbs, which grow rapidly but have shorter growth period, resulting in the nutrient restitution and aggravating the water pollution. Therefore, the wetland park needs necessary manual interventions, for example, regularly reaping and cutting the aquatic plants, to ensure the benign development of the wetland park (Chai et al. 2006; Jiao et al. 2003). Since the aim of the wetland park is to protect environment, there is no artificial landscape and avoids completely the non-administrator get into the core area of the wetland park.

3.2 Countryside Tourism Model

The pursuit of people for fine environment and healthy life is increasing with the improvement of material well-being. Countryside tourism model can meet currently these needs, so it can be as an optimization model of land use pattern for some villages where village landscape is no longer dirty and mudded but with full of fine green area. Hence, this model is beneficial for improving air quality, promoting life quality, and enhancing harmonious development of society (Ma et al. 1997). The development of model should be adaptable to the local conditions, and its forms and scales should be in accordance with local economic development and cultural tradition (Chen et al. 2002; Altieri 1999).

3.2.1 Village Public Green Land Model

In general, public green areas are developed in urban areas as more people live there together. Due to policy of reform, more and more villages have become rich in Taihu Lake watershed region. The public green lands appeared gradually in this region with different characteristics, for example, 600–6000 m^2 of subject square for cultural propaganda, public activities, and resident exercise. The optional plant species of the squares include *C. camphora, Osmanthus, C. deodara, Taxus chinensis, Platycladus orientalis, K. paniculata, Amygdalus persica, Cercis chinensis, Podocarpus macrophyllus, Pittosporum tobira, Ilex cornuta, Camellia japonica, Camellia sasanqua, Jasminum nudiflorum, Cycas revolute, Rhododendron simsii, Ligustrum quihoui, Ilex crenata cv. Convexa, Gardenia jasminoides, S. japonica, Lagerstroemia indica, Hibiscus syriacus, Parthenocissus tricuspidata, Wisteria sinensis, Ophiopogon japonicus, and Festuca arundinace.* (see Fig. 3.5).

Fig. 3.5 Village public green land (Photograph taken by Jianfeng Zhang)

3.2.2 Personal Private Courtyard Model

According to the personal preference and affordable capability, some households may gradually construct the courtyard greening, including garden courtyard, flower courtyard, fruit courtyard, forest-fruit courtyard, forest courtyard, and the like. No doubt, the garden courtyard model is suited for some rich farmers, as well as the company and factory with a larger courtyard area. In this model, trees such as *C. deodara, Osmanthus, Cymbidium, C. revolute, Ilex chinensis, Rosa chinensis, P. tobira, Buxus sinica, Malus, Paeonia suffruticosa*, and grasses are planted. If economic condition allows, the farmers may construct rockery and cistern to upgrade the taste and quality of the courtyards. Obviously, the flower courtyard model is attractive for families with substantial financial capabilities and who loves and knows the cultivation techniques of bonsai of flowers. The model may also include some shrubs and herbaceous plants. The flower courtyard not only produces leaves, flowers, and fruits, but also provides some economic benefits. The fruit courtyard model is popular for middle-income household, because this model can provide various fruits and products at all the seasons. Of course, the fruits can be used for their consumption, traded off, or given as gifts to friends. The forest-fruit courtyard model is suited for the general households. Its structure is that of planting fruit trees in front of the house and establishing forest in back of the courtyard (Zhang and Sun 2005). The forest courtyard model requires that the households accept a long-term investment and plant several valuable timber trees or landscape trees (see Figs. 3.6, 3.7 and 3.8).

Fig. 3.6 Fruit courtyard (Photograph taken by Jianfeng Zhang)

Fig. 3.7 Courtyard with economic trees in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 3.8 Garden courtyard in Yixing (Photograph taken by Jianfeng Zhang)

This courtyard model primarily focuses on social benefits, combining with ecological and economic benefits (Archer and Marks 1997).

3.3 Multiple Production Models

Multiple production refers to agricultural production of growing different plants together in the same field producing various products. In this case, land use efficiency is increased substantially. Meanwhile, land vegetation coverage is raised and consequently soil erosion is prevented or reduced (Fox et al. 1990). The production model can efficiently utilize arable lands and other natural resources such as light, air, water, soil nutrients, and the other factors in agricultural ecological system. Hence, this model will achieve rational utilization of ecological niche, improve unit yield and quality of production, decrease the amount of chemical fertilizer and pesticide application, and reduce the pollution output to agricultural system (Jixian et al. 2009; Liang et al. 2003).

3.3.1 *Open Stereoscopic Agriculture Model*

Open stereoscopic agriculture model refers to improvement and optimization of the existing farming systems and farmland structure to construct a stereoscopic model, e.g., tree–shrub–grass, tree–shrub–herb, tree–vegetable, tree–herb. The model could include some conventional vegetables. The kinds of plants include *Populus* spp., *Celtis sinensis, Schima superba, Paulownia Sieb, Phoebe sheareri, Dalbergia hupeana, C. bungei, Ginkgo biloba,* and other timber trees; *M. alba, Toona sinensis, Ulmus pumila,* and other trees for timber and leaf production; *Juglans regia, Torreya grandis, Camellia oleifera, Ailanthus altissima, Sapium sebiferum,* and other oil trees; *Medicago, Trifolium repens, Melilotus officinalis, Onobrychis viciaefolia, Astragalus sinicus,* and other grasses of *Leguminosae* sp.; *Shorttube Lycoris, Cassia obtusifolia, Rehmannia glutinosa, Salvia miltiorrhiza, Pinellia ternate, Eucommia ulmoides, Lycium, Carthamus tinctorius, Mentha haplocalyx,* and other herbaceous plants; *Cannabis sativa, Alchornea davidii, Eleusine indica, Sesbania cannabina, Juncus effuses,* and other fiber plants; Common Yam, *Lilium brownii var. viridulum, Heleocharis dulcis,* and other starch-rich plants (see Figs. 3.9 and 3.10). This model should be combined with sewage treatment and solid waste treatment in villages, forming circular production structure and achieving the large-scale and pollution-free organic agriculture (Yong and Chen 2002).

Fig. 3.9 Trees and crops intercropping in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 3.10 Pear cultivation with peanuts in Yixing (Photograph taken by Jianfeng Zhang)

3.3.2 Greenhouse Agriculture Model

Greenhouse agriculture is an important and beneficial model in regions where land is scarce or in degraded condition (Wang et al. 2002). The modern greenhouse agriculture aims to gain higher production and achieve more resource exploitation. In greenhouse agriculture, plants with higher economic benefits should be chosen, such as ornamental flowers and plants of nursery stock, plants used as industrial materials, edible mushroom, medicinal plants, and melons. At the same time, it is necessary to lay emphasis on exploiting and optimizing germplasm resources, techniques of tissue culture, and to expand and improve the core technology of modern agriculture. The exploitation of biomass resource could provide various kinds of products, e.g., industry materials, medicines, and feeding stuff, in collaboration with research institutes and colleges. The greenhouse agriculture requires the developed regional economy and technology as a foundation and runs in accordance with market demands. Obviously, it is an intensive managed production pattern, which needs higher techniques and skilled workers. Therefore, the model requires the combination of production, education, and scientific research and is committed to the high technology. No doubt, this model is significant for reducing surface runoff and controlling pollutants (see Figs. 3.11 and 3.12).

Fig. 3.11 Strawberry productions (Photograph taken by Jianfeng Zhang)

Fig. 3.12 Vegetables production (Photograph taken by Jianfeng Zhang)

3.4 Conclusions

The optimization of land use is a regional and time bound project to satisfy the human needs and environmental protection and its connotation change constantly with the development of society. We discussed some land use optimized patterns suited for the test area to protect immediately the ecological environment and to meet the realistic demands of local residents. The optimized patterns were divided into two classes, the first-class included ecological protection model, countryside tourism model, and multiple production models. The second-class had 6 subpatterns such as ecological protective forest model, wetland park model, village public green space model, private courtyard model, open stereoscopic agriculture model, and greenhouse agriculture model. Hopefully, these land use types can provide some guidelines for rational land use in order to combat NPS pollution in Taihu Lake watershed.

References

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ 74:19–31

Archer JR, Marks MJ (1997) Control of nutrient losses to water from agriculture in Europe. Proc Fertilizer Soc 6(5):405–409

Chai SW, Pei XM, Zhang YL et al (2006) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conserv 20(6):191–194

Chen JL, Shi LL, Zhang AG (2002) Controlling effects of forest belts on non-point source pollution of agricultural lands in Taihu Lake area, China. J Forest Res 13(3):213–216

Fox RH, Myers RJK, Vallis I (1990) The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin, and nitrogen contents. Plant Soil 129(2):251–259

Gao C (1999) Environmental management options practiced in Europe to mitigate agricultural nutrient pollution of ground and surface water. Agric ECO Environ 51(2):50–53

Jiao F, Qin BQ, Huang WY (2003) Management of water environment in small watershed with Hufu town of Yixing city as example. China Environ Sci 23(2):220–224

Jixian Z, Liu ZJ, Sun XX (2009) Changing landscape in the Three Gorges Reservoir area of Yangtze River from 1977 to 2005: land use/land cover, vegetation cover changes estimated using multi-source satellite data. Int J Appl Earth Obs Geoinf 11(6):403–412

Kleijn D, Verbeek M (2000) Factors affecting the species composition of arable field boundary vegetation. J Appl Ecol 37:256–266

Lee SW, Hwang SJ, Lee SB et al (2009) Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics. Landscape Urban Plann 92 (2):80–89

Lenat DR, Crawford JK (1994) Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294(3):185–199

Liang T, Wang H, Zhang S et al (2003) Characteristics of phosphorous losses in surface runoff and sediment under different land use in west tiaoxi catchment. Environ Sci 24(2):35–40

Ma LS, Wang ZQ, Zhang SM et al (1997) Pollution from agricultural non-point sources and its control in river system of Taihu Lake, Jiangsu. Acta Sci Circumst 17(1):39–47

Wang SP, Yu LZ, Xu SY et al (2002) Research of non-point sources pollution loading in Suzhou Creek. Res Environ Sci 15(6):20–23, 27

Yang GS, Wang DJ et al (2003) Economic development, water environment, water disaster. Science Press, Beijing

Yong STY, Chen WL (2002) Modeling the relationship between land use and surface water quality. J Environ Manage 66(4):377–393

Young RA (1989) A non-point source pollution model for evaluating agricultural watershed. J Soil Water Conserv 44(2):168–173

Yu XX, Yang GS, Liang T (2002) Effects of land use in Xiaotiaoxi catchment on nitrogen losses from runoff. Agro Environ Prot 21(5):424–427

Zhang JF, Qin GH (2007) Poplar-based agro-forestry in China and its economic analysis. Shandong Science and Technology Press, Jinan

Zhang JF, Sun QX (2005) Review on agroforestry systems in China. Chin Forest Sci Technol 4 (3):80–84

Zhang DD, Zhang XH, Zhang JQ et al (1997) Integrated research and evaluation on non-point source pollution in Shanghai suburbs. Acta Agric Shanghai 13(1):31–36

Zhang WL, Wu SX, Ji H et al (2004) Estimation of agricultural non-point source pollution in China and the alleviating strategies I. Estimation of agricultural non-point source pollution in China in early 21 century. Chin Sci Agric 37(7):1008–1017

Zhang JF, Fang MY, Li S (2007) Developing agroforestry in slopelands to combat non-point pollution in China. Chin Forest Sci Technol 6(4):67–72

Chapter 4
Countermeasures to Control NPS Pollution in Headwaters of Taihu Lake Basin

Abstract Water pollution in Taihu Lake has become one of the most serious environmental problems that draws public attention and needs to be solved as soon as possible. It is well known that forest could play an important role to control soil and water erosion and uptake of soil nutrients. However, the forest cover in this area is rather low, and woodlands are extensively managed in the headwaters region. Thus, the fertilizer loss resulted from the erosion of soil in sloping field has an important role in the water course. In view of this situation, enhancing forest establishment and management is significant. The primary objective of developing hedgerows was to control soil and water erosion, and to improve farming conditions on slope field in headwater region of Taihu Lake basin. Building riparian forest buffer zone is helpful to protect riverbank, uptake nutrients, hold pollutants, and provide habitat for wildlife. The planting techniques of hedgerows in slope fields and riparian forest buffer zone along channels are discussed in this chapter, which is considered as a vital measure to control agricultural non-point source pollution.

Keywords Taihu Lake · Headwaters · Countermeasures · Hedgerows · Riparian forest buffer zone · Non-point source pollution

The 2300-square-kilometer Taihu Lake, vastly located in Jiangsu Province, is the main source of drinking water for 40 million residents of surrounding area and people in neighboring Shanghai and Zhejiang. Taihu Lake is one of the five largest freshwater lakes in the country, and the gross economy of the lake basin has occupied an important position in the country (Zhang et al. 2004). However, due to the excess consumption of resources for the regional economic development, the eco-environment has been drastically deteriorated. From 1980s in last century, the water quality of Taihu Lake has descended one grade in every 10 years, and now, it has become a typical area where water quality is lacking. Although the government has given importance to combat the water pollution and taken many measures, mainly focusing on point source pollution such as industrial wastewater decontamination and lake water cleaning, the water quality of Taihu Lake is still exasperate, and the situation of water pollution is still austere. The affair of blue-green

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algae bloom occurred in May 2007 alarmed the people and the government to realize the risk and hazards of eutrophication. Hence, it is necessary to discuss the measures to control the pollutants in headwaters.

4.1 Introduction

It has been discussed that the causes of water body pollution and eutrophication problem are complicated and multiple (Daniel et al. 1998). With the rapid development of industry and the excess consumption of pesticide for agriculture, a large amount of pollutants and nutrients such as nitrogen and phosphorus are drained into the lake and surrounding channels and cause overgrowth of algae and oxygen depletion, which resulted in the severe pollution (see Figs. 4.1 and 4.2).

In view of this situation, taking measures in headwaters area to control non-point source (NPS) pollution is significant. Located upstream of the Lake, Xitiaoxi River and Dongtiaoxi River both lied in Zhejiang Province are recognized as the headwaters of the lake. In this region, local people live on the mountain range, planting bamboo and/or tea trees, and cultivating grain or cash crops. During these farming activities, agrochemicals are applied, usually at higher dose in order to have a good harvest. Moreover, soils are often disturbed naturally. During heavy rains or storms, water and soil erosion will occur, and the soil nutrients finally flow into the Lake through water (Zhang et al. 2007).

Fig. 4.1 Taihu Lake pollution in 2008 (Photograph taken by Jianfeng Zhang)

Fig. 4.2 The channel connected with Taihu Lake pollution in 2008 (Photograph taken by Jianfeng Zhang)

Meanwhile, there are several rivers flowing into Taihu Lake, most of them are from riparian zone which is lacking vegetation cover or damaged badly. It is well known that riparian plant buffer zone could play an important role in protecting riverbanks, providing wildlife habitat and uptaking pollutants. If this riparian ecosystem is absent or degraded, different kinds of agricultural, industrial, and biological waste and pollutants would enter the water and finally flow into the Lake.

Recently, the contour hedgerow crop system has become one of the major forms of agroforestry on slope field in developing countries (Baudry et al. 2000). It is proved that intercropping between the contour hedgerows is favorable for controlling soil erosion, increasing soil fertility, and gaining higher benefit of the slope field by relatively low input (Busck 2003). In addition to contour hedgerows, developing riparian forest buffer zone along rivers around Taihu Lake is also important to tackle agricultural NPS pollution in headwater region (Chai et al. 2006; Zhang et al. 2007).

4.2 Functions and Planting Techniques of Hedgerows

4.2.1 Functions of Hedgerows

Traditionally, hedgerows have acted mainly as fences for livestock and sources of a variety of wood and non-wood products (Deckers et al. 2004), in addition to a kind of landscape. At present, the importance of hedgerows for agricultural sustainability and environmental protection is becoming increasingly emphasized (de Blois et al. 2002).

Reduce soil erosion: Water flow from rain and irrigation, as well as clean cultivation and vacant field borders, can increase erosion potential. Hedgerows provide a barrier that can slow water flow and trap soil particles (Archer and Marks 1997); this is especially useful along waterways, especially in slop fields (see Figs. 4.3 and 4.4).

Conserve water: Hedgerows can be planned in combination with other practices in order to develop complete conservation systems that enhance landscape aesthetics, improve water quality, and provide wildlife habitat. Well-planned hedgerows retain water and reduce evaporation by blocking drying winds in summer.

Decrease wind damage: Wind can disturb pollination and damage fruit and flowers when plant parts thrash against each other. Plants under wind stress put energy into growing stronger roots and stems resulted in lower yields and delayed maturity. Strong winds cause grain and grass crops to lodge making harvest more difficult. Properly designed hedgerows can reduce wind speed by up to 75 % and improve crop performance (Norris et al. Norris and Batie 1987).

Moreover, hedgerows containing a mixture of native grasses, shrubs, and trees provide the greatest environmental benefits (Altieri 1999).

Fig. 4.3 Hedgerows of tea trees in Anji (Photograph taken by Guangcai Chen)

Fig. 4.4 Hedgerows of *Lycium barbarum* L. in Anji (Photograph taken by Jianfeng Zhang)

Nevertheless, consider the amount of shading a hedgerow will provide at maturity. Shading may have impact on the growth of adjacent and understory plants, microclimate, and aesthetics.

4.2.2 Techniques of Hedgerows Development

Soil preparation: It is one of the keys to successful plant survival. An easy way to establish planting areas in existing grass/pasture is to apply a thin layer of compost or manure followed by a layer or two of cardboard and cover with mulch such as straw or leaves. In large areas, this may not be practical, and hence, cover crops can be utilized. These crops improve soil fertility, reduce weeds, and attract beneficial insects. When planting in heavy clay soil, the ground could be tilled in spring and planted with cover crops, such as crimson clover in early spring followed by buckwheat, till, or disk in late summer and replant with a late sowing of over-wintering seeds (Gao 1999).

Species selection: The location, function, and size of hedgerows are the largest factors influencing plant selection. Native species adapted to local conditions benefit the wildlife. Locally grown plants, tolerant to local conditions, are likely to thrive in hedgerows, such as *Gleditsia sinensis*, *Leucaena glauca*, *Pterocarya* *stennoptera*, *Celtis sinensis*, *Kalopanax septemlobus* (thumb.), *Amorpha fruticosa*, and *Lespedeza bicolor*. Plants grown from the locally collected seed are of local provenance or origin, but this takes time, effort, and patience. A variety of species provides a varied food supply throughout the year for wildlife (Kleijn and Verbeek 2000). Different hedgerow species or climbers are included at approximately every meter, and a nurse species such as alder is included. Some perennial species such as blackberry, which are endemic, can function as excellent wildlife habitat and food crops, but are highly invasive and will require frequent maintenance.

Hedgerow layout: This is determined by the location, function, and plants selected. Hedgerows are always longer than they are wide. Although a single line of trees will provide some benefits, four or more rows of plants will offer optimal advantage for windbreaks, water and soil conservation, and habitat adequate for wildlife. The plants that are taller at maturity are placed in the center row with shorter ones interplanted between and along the edges (Barr and Gillespie 2000). A diverse variety of plants is more beneficial.

Usually, the spacing among rows is 3–7 m and among stocks is 20–60 cm.

Generally, the distance (L) between rows in slop fields is calculated by the formula:

$$L = D/\cos\alpha + B$$

where L—the distance between rows in slop fields (m), D—designed field width (m), α—hill grade, and B—row width, usually taking 0.3–0.6 m. In practice, L takes the values as in Table 4.1.

Planting hedgerows: Normally, trees/shrubs are planted in spring of the year. Some bare root plants are more difficult to establish.

Depth: Plant to the same depth as the plants were previously planted and firm in.

Spacing: Allow up to eight plants per meter. A staggered double row is preferable with plants 250 mm apart and 300 mm between rows. A single row at 300-mm spacing may be adequate, if well maintained (Schmucki et al. 2002).

Pruning: Plants of *Hippophae* spp. may be cut back to 75 mm from ground level to increase density of new shoots at this level. The planting rate is normally 5–8 plants per meter.

Maintenance: Plant only the length of hedgerow that can be maintained. Control competing vegetation to prevent smothering and allow lower branches develop, giving a dense base (Zhang et al. 2004). If other means are used to establish the hedgerow, it is essential that the riparian zone (river, creek, pond, etc.) be protected from any contamination. As plants mature, they will eventually shade most of the annual weeds.

Table 4.1 The longest distance between rows in different slope lands

Grade (°)	15	20	25	30	35	>35
L (m)	8–10	5–6	4–5	3–4	3	2–3

4.3 Techniques of Establishing Riparian Forest Buffer Zone

Within the river corridors, to some extent there has been a loss of riverside woodland and fringing vegetation and subsequent erosion of riverbanks. Wetland areas and wet woodland have been lost as a result of agricultural development. For coping with NPS pollution, riparian forest buffers are the most widely adopted agroforestry practice. Riparian buffers are typically a band of trees, shrubs, herbaceous cover, or grasses with a certain width along a stream bank. Such a band of vegetation can trap sediment and bacteria, and absorb nutrients from both polluted runoff and sub-surface flow.

Riparian forest buffers layout: Forests are typically on sites with fine soils because of their position on the landscape (Daniel et al. 1998). The riparian forest buffer design needs to provide environmental protection and economic benefits such as mid- to long-term products as farmers rely on the fields for living. For example, some of the products that could be harvested following the end of the conservation incentives at age of 10 or 15 years include decorative woody floras or short rotation crops for fuel, fodder, or paper pulp.

Generally, riparian buffer strip design employs a three-zone system; namely "Zone 1" consists of a 4.5-m-wide strip of undisturbed, existing or planted, forest whose major function is to maintain the bank stability; "Zone 2" consists of a 18-m-wide strip of managed forest where nutrient sequestering is the major function and, therefore, requires vigorous growth and periodic removal of trees; and "Zone 3" contains a 6-m-wide strip of grass that intercepts surface runoff and converts it to sheet flow or enhances infiltration so that runoff becomes shallow groundwater flow (Magette 2000).

Tree species selection: The selection of fast-growing species, such as willow, poplar, silver maple, and green ash, ensures rapid uptake of nutrients. The frequent removal of the stems of these species on 8- to 12-year rotations removes the sequestered nutrients from the site. Because these species regenerate from stump sprouts, the root systems stay intact and aboveground biomass is rapidly reproduced. As a result, soil stability is maintained and the surface remains intact.

Certain combinations of trees, shrubs, and grasses can function effectively as nutrient and sediment sinks for NPS pollutants. As an agroforestry system, the woodlot must be intentionally integrated with crops and/or livestock. It is ideal if the woodlot management included active management of both the overstory trees and some types of understory crop simultaneously to produce non-timber products. This is not just wild harvesting of some understory plants such as mushrooms, but is a very intensive management system (see Figs. 4.5, 4.6 and 4.7). Many high-value non-timber forest crops, e.g., ginseng, goldenseal, mushrooms, and decorative ferns, are cultivated under the protection of a forest canopy that has been

Fig. 4.5 The riparian buffer strip composes of trees, shrubs, and grasses in Yixing (Photograph taken by Jianfeng Zhang)

modified to provide appropriate microclimate and light conditions (Schultz 1995). Meanwhile, the timber stand improvement activities are carried out to develop the appropriate understory conditions. For example, thinning less desirable stems and pruning lower branches on the eventual crop trees can result in the production of clear timber that will eventually bring a higher economic return (Zhang 2004).

Plantlets establishment: After landform and soil conditions are improved in a target area, establishing the plant community to restore the ecosystem is crucial. Planting technique should conform to standard planting procedures and typically involves excavation of a planting "pocket," insertion of the plant, backfilling, and resloping of the adjacent soil and often providing wind and sun protection on harsh sites (Zhang and Sun 2005). The species selection, size of the rootstock, soil treatment, plant protective techniques, and density of planting are important issues. For forest establishment, a rather higher density of plantation is required as quickly reaching land cover is usually needed; on the other hand, mortality of plants is to be expected as well (see Fig. 4.8). Planting in cool wet weather in the spring and fall is encouraged. Planting woody vegetation in sparser areas of grass in previously

Fig. 4.6 The riparian buffer strip in Fengxian, Shanghai (Photograph taken by Jianfeng Zhang)

reclaimed areas a few years after grass/forb seeding should be considered in design for areas to serve as open space/wildlife habitat.

Maintenance and tending: As a rule, newly planted plantlets demand more care especially mulching.

Mulching can be accomplished before or after planting and is important for preventing water erosion, reducing wind erosion, reducing soil crusting, decreasing the impact of rainfall, insulating the soil surface, and decreasing evaporation. Mulching is more critical on slopes where erosion concerns require temporary stabilization prior to the establishment of planted vegetation. Mulching materials include straw, native grass, erosion control fabric, and others (Zhang and Qin 2007). Care should be taken with all mulch to avoid the introduction of weed seed and to avoid introducing excessive amounts of seed competitive with the established species such as fugitive wheat or barley in straw mulch.

Hence, streamside buffer strips are an effective management practice that will help make the agricultural landscape sustainable and reduce NPS inputs into surface waters, which in turn produce improvements in surface water quality, aquatic

Fig. 4.7 The riparian buffer strip along Huangpujiang River in Shanghai (Photograph taken by Jianfeng Zhang)

Fig. 4.8 The buffer zone is established along the riverbank in Yixing (Photograph taken by Jianfeng Zhang)

habitat, and aquatic communities (Young 1989). It is concluded that similar buffer strips should be established along both sides of any perennial or intermittent stream, as well as around lakes and ponds and in and around farming activities, to reduce the adverse effects of NPS pollution on surface water quality and aquatic life. The design using trees, shrubs, and native, non-bunch warm-season grasses is superior to cool-season grass buffer strips in reducing NPS pollution. The 20 m width is effective and also provides wildlife habitat and has the potential for tangible economic benefits from biomass and fiber products. Although fast-growing tree species provide the most rapid control of erosion in the site, high-quality hardwood species can also be grown as part of the design to provide the additional product options.

References

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ 74:19–31

Archer JR, Marks MJ (1997) Control of nutrient losses to water from agriculture in Europe. Proc Fertilizer Soc 6(5):405–409

Barr CJ, Gillespie MK (2000) Estimating hedgerow length and pattern characteristics in Great Britain using countryside survey data. J Environ Manage 60:23–32

Baudry J, Bunce RGH, Burel F (2000) Hedgerows: an international perspective on their origin, function and management. J Environ Manage 60:7–22

Busck AG (2003) Hedgerow planting analyzed as a social system–interaction between farmers and other actors in Denmark. J Environ Manage 68:161–171

Chai SW, Pei XM, Zhang YL et al (2006) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conserv 20(6):191–194

Daniel TC, Sharpley AN, Lemunyou JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Environ Qual 27(1):251–257

de Blois S, Domon G, Bouchard A (2002) Factors affecting plant species distribution in hedgerows of southern Quebec. Biol Conserv 105:355–367

Deckers B, Hermy M, Muys B (2004) Factors affecting plant species composition of hedgerows: relative importance and hierarchy. Acta Oecol 26:23–37

Gao C (1999) Environmental management options practiced in Europe to mitigate agricultural nutrient pollution of ground and surface water. Agric Eco Environ 51(2):50–53

Kleijn D, Verbeek M (2000) Factors affecting the species composition of arable field boundary vegetation. J Appl Ecol 37:256–266

Magette WL (2000) Monitoring. In: Ritter WF, Shirmohammadi A (eds) Agricultural non-point source pollution. LEWIS Publishers, London, pp 205–228

Norris PE, Batie SS (1987) Virginia farmers: soil conservation decisions: an application of tobit analysis. South J Agric Econ 19:79–90

Schmucki R, de Blois S, Bouchard A (2002) Spatial and temporal dynamics of hedgerows in three agricultural landscapes of Southern Quebec, Canada. Environ Manage 30:651–664

Schultz RC (1995) Agroforestry opportunities for the United States of America. Agrofor Syst 31:117–132

Young RA (1989) A non-point source pollution model for evaluating agricultural watershed. J Soil Water Conserv 44(2):168–173

Zhang JF (2004) Agroforestry and its application in amelioration of saline soils in eastern China coastal region. Forest Study China 6(2):27–33

Zhang JF, Qin GH (2007) Poplar-based agro-forestry in China and its economic analysis. Shandong Science and Technology Press, Jinan

Zhang JF, Sun QX (2005) Review on agroforestry systems in China. Chin Forest Sci Technol 4 (3):80–84

Zhang WL, Wu SX, Ji HJ et al (2004) Estimation of agricultural non-point source pollution in China and the alleviating strategies I. Estimation of agricultural non-point source pollution in China in early 21 century. Chin Sci Agric 37(7):1008–1017

Zhang JF, Fang MY, Li S (2007) Developing agroforestry in slopelands to combat non-point pollution in China. Chin Forest Sci Technol 6(4):67–72

Chapter 5
Roles of Forests in Ecological Control of NPS Pollution

Abstract Taihu Lake is the third largest freshwater lake in China, covering water area of 2428 km^2 and controls drainage area of 36,500 km^2. A large quantity of sewage is discharged into Taihu Lake region because of increase in population and economic development, which severely damaged the ecological system of the Taihu Lake region. This results in water pollution, eutrophication, and shortage of quality water which in turn affect the sustainable development of society and economy of the watershed. Based on analysis on source–sink of non-point source pollution (NPS) in Taihu Lake basin, it is concluded that the function of forests on NPS pollution control is multiple and important by both source reduction and sink expansion. The primary objective of planting trees through constructing forested wetlands and establishing riparian forest buffers is to control soil and water erosion, to decrease application of agrochemicals, and to improve farming conditions in the region of Taihu Lake basin. Moreover, forests help to intercept acidy rain, protect stream banks, uptake nutrients, hold up pollutants, and provide habitat for wildlife.

Keywords Forest · Role · Ecological control · Non-point source pollution · Riparian forest buffer zone · Source–sink · Taihu Lake

Non-point source (NPS) pollution refers to pollutants from air, ground, and soil which were drained into surface water through runoff and caused enrichment in water, resulting in pollution of water environment. The water environment was polluted by NPS pollution mainly through nutrimental and toxic pollutant. The main sources of water eutrophication are N and P from agricultural production and municipal domestic wastewater. The heavy metals from pesticide and its degradation products and chemical fertilizer, toxic organic substance, and toxic pollutants from atmospheric deposition could cause water environment pollution and affect human health.

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5.1 Current State of Pollutions

5.1.1 Loss of Chemical Fertilizers and Pesticides from Farmlands

As mentioned above, Taihu Lake watershed is an important agricultural production region in the country. When agriculture is intensively managed in the region, it requires large amount of chemical fertilizer and pesticide input which has promoted the agricultural production, but it has impaired the soil and water environment (see Figs. 5.1 and 5.2). Excessive application of nitrogen fertilizers, improper proportion of nitrogen, phosphorus, and potassium, and unreasonable applying method resulted in nitrogen fertilizer utilization rate of only 30–35 %. The remaining quantity of nitrogen fertilizer is drained into water, causing NPS pollution. Ma et al.'s (1997) study in Taihu Lake region of South Jiangsu Province showed that when applying 345 kg ha^{-1} a^{-1} of nitrogen fertilizer and 18 kg ha^{-1} a^{-1} of phosphorus fertilizer, the total nitrogen drained into water by farmland reached 3.37×10^4 t, net loss of total nitrogen was 2.55×10^4 t, total output of total nitrogen reached 54.3 kg ha^{-1} a^{-1}, net output was 35.6 kg ha^{-1} a^{-1}, and 10 % of nitrogen fertilizer from farmland was drained into water. Additionally, total phosphorus drained into water by farmland reached 440.4 t, total output of total phosphorus reached 2.39 g ha^{-1} a^{-1}, and net loss of total phosphorus was 83.3 t.

Fig. 5.1 The farmer applies chemical fertilizer in rice field (photograph taken by Jianfeng Zhang)

Fig. 5.2 The pollutants go into waters by soil and water erosion (photograph taken by Jianfeng Zhang)

Sun and Huang's (1993) study showed that nitrogen from agriculture accounted for 72–75 % of total nitrogen drained into Taihu Lake. On an average 345 kg ha^{-1} of nitrogenous fertilizer was applied to farmland in Taihu Lake region, which is about twice as that of the scientific standard (120–180 kg ha^{-1}). A large amount of nitrogen loss was drained into the lake and aggravated eutrophication. A large number of high toxic and water-soluble pesticides also impaired water quality of Taihu Lake region. Zhang et al. (1997a) estimated that more than 40 t a^{-1} of pesticides was drained into Taihu Lake through runoff and seepage in farmland in the suburb of Shanghai.

5.1.2 Pollutants from Livestock Breeding and Aquaculture

The phenomenon of livestock excrement polluting the surface water has become the most conspicuous problem of agricultural non-point pollution in Taihu Lake region (see Figs. 5.3 and 5.4). Some research studies have estimated that utilization rate of pig manure was 80 %, manure of cattle, sheep, and poultry was 90 %, livestock urine was 10 %, and the unutilized excrement was flown into river. The livestock excrement in Shanghai suburbs reached up to about 7×10^6 t a^{-1}. Among them,

Fig. 5.3 Grazing cattle at upstream waters of Taihu Lake (photograph taken by Jianfeng Zhang)

Fig. 5.4 Aquaculture at the channel connected with Taihu Lake (photograph taken by Jianfeng Zhang)

pig excrement accounted for 65 %, average load quantity of plow was 18 t ha^{-1}, and the excrement flown into water environment was 2.06×10^6 t a^{-1} and accounted for 29.64 % of total excrement. Consequently, this excrement seriously polluted water quality. The river water was almost devoid of dissolved oxygen in the high-load region of livestock excrement, and COD (Chemical Oxygen Demand) was up to 200 mg L^{-1} (Zhang et al. 1997a). Extended area of blocked-web aquaculture, increased density of the aquaculture, extensive management, leftover bait, and aquatic excrement aggravated the water quality pollution and eutrophication (Gu et al. 2003).

5.1.3 Domestic Sewages

With rapid development of urbanization in Taihu Lake region, domestic sewages from small- and medium-sized cities, towns caused the non-point source pollution to a greater extent. The domestic pollution includes domestic sewage and human fecaluria. The research study showed that Shanghai suburb had 3.936×10^6 of rural population and 1.657×10^6 of urban population in 1993; generated 2.98×10^8 t a^{-1} of domestic sewage which included 3.179×10^3 t a^{-1} of TN, 795.4 t a^{-1} of TP, and 3.1793×10^4 of COD; and generated 2.04×10^6 t a^{-1} of human urine which contended 1.5748×10^3 t a^{-1} of TN, 270 t a^{-1} of TP, and 1.0198×10^4 of COD. Meanwhile, P from domestic pollution accounted for 21.71 % of the equivalent standard pollution load which is next to pollution load from livestock manures. Based on the analysis of various types of N non-point source pollution in Xueyan town of first-class nature reserves of Taihu Lake, the research showed that domestic sewages and human fecaluria from city, town, and countryside contributed 18.9 and 7.2 % of total N emission, respectively (Zhang et al. 1997b) (see Figs. 5.5 and 5.6).

5.1.4 Atmospheric Deposition

Atmospheric dry and wet deposition is associated with atmospheric pollution and meteorological conditions. The dry deposition is significant during the interval of rainfalls and its deposition rate is usually slight smaller than the wet deposition. Gravity action determines the primary mechanisms of atmospheric dry deposition. But internal impact, electrostatic attraction, adsorption, and chemical reaction among tiny particles (≤ 1 μm) are important factors that affect dry deposition. Precipitation as a fine carrier and sweeper of atmospheric pollutants contains various pollutants, such as acids, toxic metal, organic matter, N, and P, resulting in surface water pollution. Rainfall is abundant in Taihu Lake region with 1010–1400 mm of annual

Fig. 5.5 Usually domestic sewages are directly discharged into the channel connected with Taihu Lake (photograph taken by Jianfeng Zhang)

Fig. 5.6 Where go domestic sewages from these people (photograph taken by Jianfeng Zhang)

average precipitation. Hence, the occurrence frequency of acid precipitation is high in this region. Yang et al. (2001) concluded that TN, PO_4^{3-} and COD brought into Taihu Lake by rainfall accounted for 9.8–15.5 % of TN, 1.9–2.2 % of TP, and 3.5–6.0 % of COD discharged into the lake in the same period, respectively. So wet deposition caused by the atmospheric pollution, especially of nitrogen compound pollution from acid rain, is an important factor for eutrophication of Taihu Lake and is one of the important sources of non-point source pollution.

5.1.5 Diffuse Sources of Pollutions

Ground surface in cities and towns, such as commercial districts, roads, parking plots, and construction sites, usually gathered a series of pollutants, such as oils, salts, nitrogen, phosphorus, toxic substances, and municipal wastes. When rainfall and runoff scoured the pollutants on ground surface and drained into rivers and lakes, which resulted in surface water pollution. So it cannot be ignored that rapid urbanization in Taihu Lake region will worsen non-point source pollution. The line source pollution from road transport also is to be paid a great attention. According to research done by US (United States) Environmental Protection Agency (1977), the transport directly contributed 0.7 g km^{-1} $vehicle^{-1}$ of solid particulates, including 0.2 g km^{-1} $vehicle^{-1}$ of vehicle emission and 0.125 g km^{-1} $vehicle^{-1}$ of vehicle tire attrition. Therefore, non-point source pollution from road runoff in Taihu Lake region with road networks development should be further investigated.

5.2 Influencing Factors for Occurrence of Non-point Source Pollution

5.2.1 Land Use Types

Land use types and land use structure have a significant impact on pollutants loss and pollution occurrence. Certainly surface cover influences the rainfall–runoff process and then affects the pollution degree, which results in an obvious difference of non-point source pollution among different land use types. The results of the pollution load of 4 surface runoffs (paddy field, non-irrigated land, countryside, and town) in Shanghai suburbs showed that both TP and NH_3–N of surface runoff in countryside were the highest among 4 surface runoffs and up to 1.68 mg L^{-1} and 3.28 mg L^{-1}, respectively (Zhang et al. 1997a). Simulating experiments of Xitiao River region in the upstream of the Taihu Lake (Yu et al. 2002; Liang et al. 2002, 2003) indicated that under the condition of the same rainfall, the loss rate and loss quantity of nitrogen and phosphorus present big differences among different land use types and land use structures. Total nitrogen loss quantity in samrin site was the highest and paddy field had the minimum loss with surface runoff. The samrin site also had the maximum phosphorus loss, which was as much as 5 times higher than in paddy field and in pinetum. Thereby, Wang et al. (2002) drew a conclusion for different land use types in Suzhou River watershed that the average pollution load of TN from paddy field, non-irrigated land, seeding garden, countryside, and urban area was 19.19, 19.48, 6.30, 24.81, and 14.96 kg ha^{-1} a^{-1}, respectively; the average pollution load of TP was 2.86, 3.19, 2.24, 9.60, and 4.26 kg ha^{-1} a^{-1}. Obviously, land use types have a larger influence on the occurrence non-point source pollution. However, it is worthy to point out that the largest source of TN in all pollutants drained into Taihu Lake was from agricultural production, while the largest source of TP in all pollutants drained into Taihu Lake was domestic sewages.

Besides, many natural factors such as soil type, soil structure, soil texture, terrain, slope, and rainfall intensity and its duration all influence the soil erodibility and the loss of soil-soluble pollutants and have an important impact on non-point source pollution. Thus, it is significant to improve these factors by ecological measures for preventing and reducing surface runoff.

5.2.2 Farming Systems

Farmland management includes tillage method of farmland, quantity of fertilizer and pesticide application, irrigation methods, and so on (Zhang et al. 2000). Various farming systems will lead to different pollutions when irrationally performed in farmlands. The research studies have indicated that the application quantity of pesticides and their application time have greater influence on the loss of water-soluble pesticides (Pan et al. 2003). Therefore, it can be inferred that rational and efficient fertilizer practices are conducive to control agricultural non-point source pollution caused by loss of N and P. In the farmland ecological system in Taihu Lake region, migration and leaching loss of N, P, and other water pollutants changed with rotation pattern, crop species, and fertilization activity. In this situation, the key to resolve the problem is developing forest buffers between farmlands and channels to intercept and purify N, P, and other soluble substances in runoff water, which is particularly vital to control agricultural non-point source pollution (Chen et al. 2002a).

5.3 Functions of Forests on Ecological Control of NPS Pollution

5.3.1 Source Reduction

As discussed above, for NPS pollution control, forests function as both source reduction and sink expansion.

5.3.1.1 Interception of Acidy Rain

With industrial development and increased urbanization, acidy rain occurred widely and frequently on the earth, affected the waters and soils as well as forests and understory plants, and became one of the important sources of (NPS) pollution (Daniel et al. 1998; Gao 1999).

When acidy rain falls on a forest, a complex process begins. Firstly, the tree canopy sheltered and nullified the impact of raindrops, reducing the rain to a thin mist below the canopy, even in the most torrential showers. There is slight measurable soil loss from mature forests, exceeding soil formation in forests. If the rain is light, little of it penetrated below the canopy, but a film of water spread across the leaves and stems, and trapped there by surface tension (Altieri 1999). The cells of the tree absorb the required quantity and the remainder will evaporate to air.

In the stem bases of palms, plantains, and many epiphytes, or the flanged roots of figs, water is held as aerial ponds, often rich in algae and mosquitoes. Stem mosses and epiphytes absorbed many times their bulk of water, and the tree itself directed water via insloping branches and fissured bark to its tap roots, with spiders catching their share on webs, and fungi soaking up what they needed. Some trees trailed weeping branches to direct throughfall to their fibrous peripheral roots (Baudry et al. 2000). Through the interception of forests, harmful effect of acidy rain on waters and soils can be alleviated to some extent. In fact, the degree of interception of rainfall is more influenced by tree species, stand age, crown thickness, crown density, season, intensity of acidy rain, and evaporation after rain (Deckers et al. 2004).

5.3.1.2 Reduction in Water and Soil Erosion

It is widely understood that water flow from rain and irrigation, as well as, clean cultivation and vacant field borders could increase erosion potential. However, forests provide a barrier that could slow water flow and trap soil particles (Archer and Marks 1997). In forested land, below the humus lies the tree roots, each clothed in fungal hyphae and the gels secreted by bacterial colonies. About 30–40 % of the bulk of the tree itself lied in the soil; most of this extends over many hectares, with thousands of kilometers of root hairs lying mat-like in the upper 60 cm of soil (only 10–12 % of the root mass lied below this depth, but the remaining roots penetrate as much as 40 m into the rocks below). The root mat actively absorbs the water and transports it up the tree, and tree transpires it to air. This is useful especially along waterways and slope fields (Zhang and Sun 2005). In this context, trees should be planted in combination with other practices in order to develop complete conservation system that enhance landscape aesthetics, improve water quality, and provide wildlife habitat. Well-planned forest shelterbelts retain water and reduce evaporation by blocking drying winds in summer (see Figs. 5.7 and 5.8).

Fig. 5.7 Shelterbelts protect farmlands in Yixing (photograph taken by Jianfeng Zhang)

Fig. 5.8 Shelterbelts protect river banks in Yixing (photograph taken by Jianfeng Zhang)

5.3.1.3 Reduced Application of Chemical Fertilizer

Intercropping is a feasible and practical land use system in the basin region. Through long-term practice, it was found that many trees could harmoniously grow together with crops in the same field and at the same time, of which some could fix nitrogen, e.g., leguminous trees, and enrich the soil when their residues decompose (Zhang 2004). Trees also improved the soil conditions in other ways. Leaf litter decomposed and added tilth as well as nutrients to the soil. Even the root system, with its rhizobia and related communities of organisms, released nutrients and improved soil structure when it decomposed. Moreover, some trees captured nutrients too deep in the soil for crops to reach, and brought these nutrients up to the surface and back to the soil as litter, where the crops could utilize them when the litter decomposed (Schultz 1995). Furthermore, these deep roots could reduce the leaching of nutrients from soil following heavy rains and conserve soil moisture by adding mulch and litters. By all these processes, soil fertility could be maintained or improved naturally to help crops growing and less chemical fertilizers can be applied to the fields (Zhang and Qin 2007).

5.3.2 Sink Expansion

As mentioned earlier, there are different ways of pollutants output when eutrophication occurred in the water body. During NPS pollution combating process, developing forested wetland and riparian forest buffer zone is significant for sink expansion.

5.3.2.1 Developing Forested Wetlands

The ecotones between lakes and terrestrial ecosystems are crucial for protection of the lake ecosystem against anthropogenic impact (Young 1989). In view of the situation in Taihu Lake basin like increasing population and surrounding lands mainly using for agriculture, development of artificial wetlands is an attractive and cost-moderate solution to pollution by diffuse sources and even waste water.

As indicated in Table 5.3, forested wetlands were able to cope with the nitrogen and heavy metal pollution compared to other type of wetlands. They prevented, to a certain extent, penetration of undesirable components into the lake and protected the most vulnerable ecosystems, which were often lakes and reservoirs. The denitrification potential of wetlands was often surprisingly high. As much as 2000–3000 kg of nitrate-nitrogen could be denitrified per hectare of wetlands per year, depending on the hydraulic conditions (Gao 1999). This was of great importance for the protection of lakes, because a significant amount of nitrate was released by

Table 5.3 Characteristics of different type of wetlands adjacent to lakes

Type of wetland	Characteristics	Ability to retain diffuse pollutants
Wet meadows	Grassland with waterlogged soil. Standing water for a part of the year	Denitrification only in standing water. Removal of nitrogen and phosphorus by harvest
Fresh water marshes	Reed grass dominated, often with peat accumulation	High potential for denitrification, which is limited by the hydraulic conductivity
Forested wetlands	Dominated by trees, shrubs. Standing water not always for the entire year	High potential for denitrification and accumulation of pollutants, provided that standing water is present

Fig. 5.9 Forested wetland around Taihu Lake banks (photograph taken by Jianfeng Zhang)

agricultural activities. As much as 100 kg nitrate-nitrogen per hectare was found in the drainage water from intensive agriculture.

It is essential to properly plan the location of forested wetlands, as their effects are dependent on the hydrology (i.e., they should be covered by water most of the year and have a sufficient retention time to allow them to solve the considered and specific pollution problems), and on the landscape pattern (see Figs. 5.9 and 5.10).

Fig. 5.10 Forested wetland in fields (photograph taken by Jianfeng Zhang)

Chen et al. (2002b) showed the effect of forest on water environment protection is vital. When the width ratio of farmland to forest belt was 100–40, the purification effect on the losing nutrients was the best and 50.05 % N loss and 29.37 % P loss could be absorbed by forest under rape–rice rotation and 30.98 % N and 86.73 % P could be absorbed by forest under wheat–rice rotation. Under this circumstance, the purifying ability of water is very satisfactory. When the width ratio of farmland to forest belt was 150–40, 33.37 % N loss and 19.58 % P loss could be absorbed by the forest under rape–rice rotation, while under wheat–rice rotation 20.65 % N loss and 57.82 % P loss could be absorbed. There was only some purification effect when the width ratio of farmland to forest belt was 200–40. Therefore, the width ratio of farmland to forest between 100–40 and 150–40 is suitable, because it could not only purify water, but also occupy less farmland.

For species selection, besides trees such as *Nyssa aquatica*, *Liquidambar styraciflua*, *Quercus nuttallii*, the following emergent macrophyte species were proposed to be used in forested wetlands: cattails, bulrush, reeds, rushes, papyrus, and sedges. Submerged species could be grown in deep-water zones (Zhang et al. 2007). Species that could be used for this purpose include coon tail or horn wart, redhead grass, widgeon grass, wild celery, and water milfoil.

5.3.2.2 Establishing Riparian Forest Buffers

Generally speaking, riparian forest buffers are typically a band of trees, shrubs, herbaceous cover, or grasses with a certain width along a stream bank. Such a band of vegetation could trap sediment and bacteria and absorb nutrients from both polluted runoff and subsurface flow.

Riparian forest buffers were typically on sites with fine soils because of their position on the landscape. So the riparian forest buffer design must provide not only environmental protection but also economic benefits such as mid- to long-term products as farmers rely on the fields for living. For example, some of the products that could be harvested following the end of the conservation incentives at age 10 or 15 years included decorative woody floras or short-rotation crops for fuel, fodder, or paper pulp.

Certain combinations of trees, shrubs, and grasses could function effectively as nutrient and sediment sink for pollutants (de Blois et al. 2002). As a special land use system, the woodlot must be intentionally integrated with crops and/or livestock. It is ideal if the woodlot management included active management of both the overstory trees and some type of understory crop simultaneously to produce

Fig. 5.11 Wide belts forest buffers in Yixing (photograph taken by Jianfeng Zhang)

non-timber products. This is not just wild harvesting of some understory plants such as mushrooms, but was a very intensive management system. Many high-value non-timber forest crops, e.g., ginseng, goldenseal, mushrooms, and decorative ferns are cultivated under forest canopy modified to provide appropriate microclimate and light conditions (Schultz 1995). Meanwhile, the timber stand improvement activities were carried out to develop the appropriate understory conditions. For example, thinning less desirable stems and pruning lower branches on the eventual crop trees could result in the production of clean, knot-free wood that would bring a higher economic return (Zhang et al. 2004).

Hence, streamside buffer strips is an effective management practice that would help to make the agricultural landscape sustainable and reduce non-point source inputs into surface waters, which in turn produce improvements in surface water quality, aquatic habitat, and aquatic communities (Kleijn and Verbeek 2000).

It is concluded that similar buffer strips should be established along both sides of any perennial or intermittent stream, as well as around lakes and ponds and in and around farming activities, to reduce the adverse effects of NPS pollution on surface water quality and aquatic life (see Figs. 5.11, 5.12, and 5.13).

Fig. 5.12 Multiple species forest buffers in Yixing (photograph taken by Jianfeng Zhang)

Fig. 5.13 Forest buffers with simple structure in Yixing (photograph taken by Jianfeng Zhang)

5.4 Discussion and Conclusions

Located at the center of Changjiang delta region, the Taihu Lake and its effluent rivers are important sources of water for the inhabitants and rapidly increasing industrial factories in Shanghai, Wuxi, Suzhou, and other neighboring cities. Therefore, the pollution of the lake is a serious social concern.

The pollutants originated mainly from acidy rain, domestic sewage of the vast number of inhabitants, livestock manure, agricultural fertilizers, and pesticides applied over fields in the drainage basin, and the industrial sewage of more than 700 factories and mines. Due to various pollutants, the lake water is getting highly eutrophic, with frequent blooms of blue-green algae even in early summer or late autumn annually. Compared with point source pollutants, diffuse pollution is much complicated and difficult to control. Thus, combating NPS pollution needs much greater attention.

Based on analysis on source–sink of NPS pollution in Taihu Lake basin, it is concluded that the function of forests on NPS pollution control is multiple and significant.

In view of the fact that the Taihu Lake area is having more population and less land area, developing reasonable land use system is crucial to maintain regional socioeconomic sustainable development. It was proved that intercropping is favorable for controlling soil erosion, increasing soil fertility, and gaining higher benefit of the slope field with relatively low input (Busck 2003). Besides this, developing riparian forest buffers along rivers around Taihu Lake is also significant to tackle agricultural NPS pollution in headwater region.

Widely developed forested wetlands acted mainly as sources of a variety of wood and non-wood products, in addition to a kind of landscape. At present, the importance of wetlands for agricultural sustainability and environmental protection is being increasingly emphasized.

References

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ 74:19–31

Archer JR, Marks MJ (1997) Control of nutrient losses to water from agriculture in Europe. Proc Fertilizer Soc 6(5):405–409

Baudry J, Bunce RGH, Burel F (2000) Hedgerows: an international perspective on their origin, function and management. J Environ Manage 60:7–22

Busck AG (2003) Hedgerow planting analyzed as a social system–interaction between farmers and other actors in Denmark. J Environ Manage 68:161–171

Chen JL, Shi LL, Zhang AG (2002a) Controlling effects of forest belts on non-point source pollution of agricultural lands in Taihu Lake area, China. J For Res 13(3):213–216

Chen JL, Pan GX, Zhang AG et al (2002b) The controlling effects of shelter forest on non-point source pollution of agricultural lands in Taihu Lake area. J Nanjing For Univ (Natural Sciences Edition) 26(6):17–20

Daniel TC, Sharpley AN, Lemunyou JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Environ Qual 27(1):251–257

de Blois S, Domon G, Bouchard A (2002) Factors affecting plant species distribution in hedgerows of southern Quebec. Biol Conserv 105:355–367

Deckers B, Hermy M, Muys B (2004) Factors affecting plant species composition of hedgerows: relative importance and hierarchy. Acta Oecol 26:23–37

Gao C (1999) Environmental management options practiced in Europe to mitigate agricultural nutrient pollution of ground and surface water. Agric Eco-environ 51(2):50–53

Gu XH, Wang XR, Hu WP (2003) Effect of Fishery development on water environment and its eco-countermeasure in east Lake Taihu. Shanghai Environ Sci 22(10):702–704

Kleijn D, Verbeek M (2000) Factors affecting the species composition of arable field boundary vegetation. J Appl Ecol 37:256–266

Liang T, Zhang XM, Zhang S et al (2002) Nitrogen elements transferring process and fluxes under different land use in west Tiaoxi catchment. Acta Pedol Sin 57(4):389–396

Liang T, Wang H, Zhang S et al (2003) Characteristics of phosphorous losses in surface runoff and sediment under different land use in west Tiaoxi catchment. Environ Sci 24(2):35–40

Ma LS, Wang ZQ, Zhang SM et al (1997) Pollution from agricultural non-point sources and its control in river system of Taihu Lake, Jiangsu. Acta Sci Circumst 17(1):39–47

Pan GX, Zhu QH, Zhang Y et al (2003) Minimum application rates for high-yielding rice production system in the Taihu Lake region as a field measure for controlling N and P agricultural loading. Environ Sci 24(3):96–100

Schultz RC (1995) Agroforestry opportunities for the United States of America. Agrofor Syst 31:117–132

Sun SC, Huang YP (1993) Taihu Lake. Maritime Press, Beijing

U S Environmental Protection Agency (1977) Control of reentrained dust from paved street, EPA 905/9-77-007. USEPA, Kansas City
Wang SP, Yu LZ, Xu SY et al (2002) Research of non-point sources pollution loading in suzhou creek. Res Environ Sci 15(6):20–23, 27
Yang LY, Qin BQ, Wu RJ (2001) Preliminary study for potential impacts on the aquatic environment of Lake Taihu by acid rain. J Lake Sci 13(2):135–142
Young RA (1989) A non-point source pollution model for evaluating agricultural watershed. J Soil Water Conserv 44(2):168–173
Yu XX, Yang GS, Tao Liang (2002) Effects of land use in Xiaotiaoxi catchment on nitrogen losses from runoff. Agro-Environ Prot 21(5):424–427
Zhang JF (2004) Agroforestry and its application in amelioration of saline soils in eastern China coastal region. For Study China 6(2):27–33
Zhang JF, Qin GH (2007) Poplar-based agro-forestry in China and its economic analysis. Shandong Science and Technology Press, Jinan
Zhang JF, Sun QX (2005) Review on agroforestry systems in China. Chin For Sci Technol 4 (3):80–84
Zhang DD, Zhang JQ, WangYG (1997a) The main non-point source pollution in Shanghai suburbs and harness countermeasure. Shanghai Environ Sci 16(3):1–3
Zhang DD, Zhang XH Zhang JQ et al (1997b) Integrated research and evaluation on non-point source pollution in Shanghai suburbs. Acta Agric Shanghai 13(1):31–36
Zhang DD, Zhang XH, Chen PQ (2000) Affecting factors and pollution prevent and control of water soluble pesticides in rice field draining loss. Shanghai Environ Sci 19(8):388–390
Zhang WL, Wu SX, Ji HJ et al (2004) Estimation of agricultural non-point source pollution in China and the alleviating strategies I. Estimation of agricultural non-point source pollution in China in early 21 century. Chin Sci Agric 37(7):1008–1017
Zhang JF, Fang MY, Li S (2007) Developing agroforestry in slopelands to combat non-point pollution in China. Chin For Sci Technol 6(4):67–72

Chapter 6
Develop Urban Forestry to Prevent Surface Runoff and Eutrophication

Abstract At present, China faces various environmental problems such as air pollution, noise, soil erosion, of which water pollution is the vital issue. In order to cope with the problem, it is significant to develop urban forestry (mainly shelter belts), because forests have highly modified soils that promote infiltration of water, thereby reducing surface runoff, preventing nonpoint source pollution. Organic matter, roots, and soil fauna maintain the porosity and permeability of the forest floor, and evapotranspiration keeps soil unsaturated. While the replacement of forested areas with impervious surfaces increases runoff, prevents infiltration, and leads to elevated levels of phosphorus loading and eutrophication of waterways. Thus, by building forest shelter belts they can protect waterways and produce clean water by controlling surface runoff, flooding, and erosion, and promoting infiltration of water into forest soils.

Keywords Coastal region · Urban forestry · Water pollution · Eutrophication · Ecological benefits · Surface runoff · Environmental problem

There is 18,000 km coastal line in China. Owing to the natural conditions and fine sites, the coastal region becomes one of the most developed and populated areas in the country. Along China's continental coastline, population densities average between 110 and 1600 per square kilometer. In some coastal cities such as Shanghai, China's largest with 17 million inhabitants, population densities average over 2000 per square kilometer, located at the estuary of the Yangtze River, is the largest economic center and an important port city in China, with a land area covering 6340 square kilometers. With socioeconomic development, nonpoint source pollution is getting serious in this area.

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6.1 Introduction

East China Sea (ECS) is a marginal sea characterized by both shallow and deep-water features. The bathymetry of ECS is very complicated. Its western part is occupied by continental shelf covering about two-thirds of the total area, and the southern part is occupied by the continental slope and is deep trough (Okinawa Trough), with a maximum depth exceeding 2700 m. The sea surface is also affected by the monsoon, the direction changing twice a year. Since materials carried by the Kuroshio Current and summer monsoon eastward into the ocean current from ECS are not contaminated, the main sources of pollutants are the Yellow Sea and the eastern rivers, coasts, and the atmosphere of the Chinese mainland. Yangtze River is the main source of land-based pollutants discharging into ECS.

In the past two decades, the ECS environment has faced huge stresses from anthropogenic activities and population growth in the Yangtze River drainage basin and the coastal areas. Many pollutants from land-based sources, such as sewage, oil hydrocarbons, sediments, nutrients, pesticides, litter and marine debris, and toxic wastes, enter the sea with river water and other runoff from land (see Figs. 6.1 and 6.2). Pollutants constitute a threat to coastal and marine ecosystems as well as to the health of coastal inhabitants by limiting phytoplankton growth, increasing the mortality of fish and benthos, increasing eutrophication, red-tide occurrence, decreasing fishery yields, and non-reversible changes in ecosystem health, of which

Fig. 6.1 One corner of the East China Sea shore (Photograph taken by Jianfeng Zhang)

Fig. 6.2 The channel connected with the East China Sea (Photograph taken by Jianfeng Zhang)

water pollution is the vital issue (Zhang et al. 2009). In order to cope with the problem, it is significant to develop urban forest shelter belts to prevent nonpoint source (NPS) pollution in coastal region.

6.2 Eutrophication and Its Implications for Coastal Ecosystem

6.2.1 The Big Pressure on the Coastal Environment

There is a big pressure on the coastal environment coming from both natural and anthropogenic driving forces that interact in various ways (Altieri 1999). Coastal areas' dynamic nature results from the exchange of matter and energy between land and sea. The natural processes such as the dynamics of alluvia and natural sedimentation which determines nutrient and energy flows are being modified by human activities. They affect water flows by constructing dams, extracting water, or deviating rivers. They also affect erosion especially by deforestation. The reducing or blocking of sediment supply can slow down the vertical accretion—aggravating salt-water intrusion problems (Zhang and Shan 2009). On the other hand, it can give rise to the retreat of the coastline through wave erosion.

6.2.2 The Concept of Eutrophication

Eutrophic means nutrient-rich and eutrophication literally means enrichment with nutrients, although nowadays the term is more often used in a negative sense to mean over-enrichment (Archer and Marks 1997). Indeed in addition to carbon, oxygen, and hydrogen that plants can find directly from water and carbon dioxide in the atmosphere, two major nutrients are necessary for the development of aquatic life: nitrogen (N) and phosphorus (P). A third one, silica (Si), is necessary for the development of diatoms (Chai et al. 2006). Natural eutrophication is the process by which water body is gradually getting older and become more productive. It normally takes thousands of years to progress. But the presence of excessive nutrients can seriously disturb this natural eutrophication process and the functioning of marine ecosystems and humans, through their various cultural activities, has greatly accelerated this process.

6.2.3 Implications of Eutrophication on Coastal Ecosystem

Under normal conditions—without the eutrophication, macrophytes at the bottom of the water develop normally, the amount of phytoplankton is such that light can penetrate down to the bottom and fish and shellfish can live and reproduce. If the amount of nutrient increases, mainly short-living macrophytes (e.g., pelagic macroalgae) will grow much faster and larger and new species will develop (Daniel et al. 1998). These will compete with those (e.g., sea grasses or benthic plants) originally present. In some cases, phytoplankton will also multiply. This development of macrophytes, including free-floating algae, and phytoplankton, will prevent a large proportion of the light from reaching the bottom. The first signs of the reduction of oxygen concentration will become visible.

Indeed, the oxygen content of bottom waters is determined by the balance between supply and consumption. Oxygen is transported to the bottom areas primarily through mixing with surface waters, or via inflow of bottom waters from other areas. Oxygen is consumed in the respiration of living organisms and the decomposition of organic matter. During periods of limited supply and large consumption, oxygen depletion may occur. Eutrophication leads to increased oxygen consumption and therefore increases the risk of oxygen depletion. If the oxygen is completely exhausted, hydrogen sulfide is formed. Oxygen depletion and, even more so, the presence of hydrogen sulfide constitute a serious threat to the bottom fauna. The risk is greatest in the deepest sections of water.

When the situation become extreme, oxygen concentrations will reach levels that make aquatic life impossible. Only those species that require very little oxygen will survive on these conditions. The amount of organic sediment will increase, as will the demand in oxygen. The final step will be the end of all aerobes.

The major consequence of eutrophication concerns the availability of oxygen. Plants, through photosynthesis, produce oxygen in daylight. On the contrary, in darkness all animals and plants, as well as aerobes and reducers, respire and consume the oxygen. These two competitive processes are dependent on the development of the biomass. But short-lived algae may die and sink to the bottom of the sea, where their decomposition uses up oxygen (Zhang and Jiang 2010). In the case of severe biomass accumulation, the process of oxidation of the organic matter that has formed into sediment at the bottom of the water body will consume all the available oxygen. Thus, the water will loose all its oxygen and all life will disappear. This is accompanied by specific smell of rotten eggs.

In parallel with these changes in oxygen concentration, other changes in the water environment occur:

1. Changes in algae population: During eutrophication, macroalgae, phytoplankton (diatoms, dinoflagellates, and chlorophytes), and cyanobacteria, which depend on nutrients, light, temperature, and water movement, will experience excessive growth. From a public health point of view, the fact that some of these organisms can release toxins into the water or be toxic themselves is important (Altieri 1999; Daniel et al. 1998)
2. Changes in zooplankton, fish and shellfish population: When eutrophication occurs, this part of the ecosystem is the first to demonstrate changes. Being most sensitive to oxygen availability, these species may die from oxygen limitation or from changes in the chemical composition of the water such as the excessive alkalinity during intense photosynthesis.

Being the result of a natural process, eutrophication remains above all the consequence of human activities. NPS pollution, especially agricultural pollution may be the main cause of nutrient adding in watercourses and consequently the main cause of eutrophication.

6.3 Causes of Eutrophication

It is well known that there are many causes to lead to eutrophication (Gao 1999), for example, hydromodification which refers to channelization (the straightening, widening, or deepening of channels for flood control or navigation), dam construction and dam use, and stream bank and shoreline erosion. Channelization increases water flow rates and changes water flow pathways. This may cause nonpoint source (NPS) pollution by both increasing erosion rates and increasing the quantity of pollutants reaching downstream sites. Dam construction may increase erosion and sediment problems and may also result in the release of contaminants from construction equipment (such as oil and fuel), which enter the waterway. Dams may cause other NPS pollution problems because sediment and other pollutants build up behind the dam. Generally speaking, this case occurs few, more often happened is the followings:

6.3.1 Agricultural Sources

The pesticides and fertilizers applied to cropland become nonpoint sources of pollution when they are washed into waterways by rainfall or snow melt. In addition, erosion of soil can lead to increased sediment levels in waterways, another type of nonpoint pollution (Young 1989). Finally, runoff can carry animal wastes from holding pens or grazing fields into waterways.

6.3.2 Urban Sources

A wide variety of urban sources of NPS pollution degrade coastal waters. Urban development increases impervious surfaces (surfaces that do not allow water to seep through, such as asphalt). Rain water and snow melt quickly run off these surfaces without being absorbed. Since these surfaces are often covered with oil, trash, animal wastes, and other contaminants, the rain water and snow melt pick up and carry these contaminants to surface water bodies. Failing septic systems, which contribute bacteria and chemicals to coastal waters, is another major source of urban nonpoint source pollution. Finally, roads, highways, and bridges also contribute to NPS pollution. Oil, antifreeze, and other contaminants leaked onto these surfaces, as well as residue left from tires and exhaust, can be washed into surface water bodies.

6.3.3 Marinas/Boats

Marinas and boatyards are a source of several types of contaminants, including fuel, cleaning chemicals, paint, and oil. These facilities cause NPS pollution when these substances are spilled directly into the water or are washed off docks and boats when it rains. Boats are also a source of NPS pollution, including sewage and trash that is purposefully released to the water, and gasoline and oil that accidentally leaks from engines (see Figs. 6.3 and 6.4).

Fig. 6.3 Tourism boats of the East China Sea in Ningbo (Photograph taken by Jianfeng Zhang)

Fig. 6.4 Cargo ships of Huangpujiang river linked with the East China Sea in Shanghai (Photograph taken by Jianfeng Zhang)

6.4 Functions of Urban Forestry

Forests are critical for producing and purifying the nation's water supply which protect waterways and produce clean water by controlling surface runoff, flooding and erosion, and promoting infiltration of water into forest soils, where it is purified by biotic and abiotic processes. Mature forests have the most consistent water yields and are best at moderating flow and controlling surface runoff (see Figs. 6.5, 6.6 and 6.7). A number of physical factors affect the rates of infiltration and surface runoff such as soil permeability, soil depth, and slope. Studies have shown impervious surface coverage to be strongly negatively correlated with water quality, with stream degradation occurring at low levels (10–20%) of watershed imperviousness (Chen et al. 2002).

Phosphorus pollution, the primary cause of algal blooms in lakes, may exceed total maximum daily load limits set by the state in some reservoirs if residential impervious surfaces exceed 10 percentage.

Fig. 6.5 Urban forest in Xiamen city (Photograph taken by Jianfeng Zhang)

Fig. 6.6 Urban forest in Gulangyu Island around by East China Sea (Photograph taken by Jianfeng Zhang)

As one special type of forest ecosystem, forested wetlands also provide many important environmental and economic benefits (Zhang et al. 2007). Wetlands help to control flooding, protect the shoreline from storm damage, and provide habitat for commercial fish and shellfish, as well as rare and endangered species. In terms of NPS pollution, wetlands can hold sediments and other contaminants, which can keep these contaminants from reaching coastal waters (Deckers et al. 2004). When wetland areas are filled or otherwise altered for development, the wetlands no longer serve this function, and NPS pollution problems are increased. In addition, when the natural capacity for wetlands to hold contaminants is surpassed, wetlands release these contaminants to coastal waters (Kleijn and Verbeek 2000). Wetlands protection is therefore important to the protection of coastal resources. In addition, wetland restoration (i.e., returning wetlands to their former and more productive natural function, condition, or size) and the construction of artificial wetlands should be encouraged to further protect coastal waters.

Fig. 6.7 Urban forest in Fuzhou city (Photograph taken by Jianfeng Zhang)

6.5 Conclusions

The quality of drinking water in rivers, lakes, and reservoirs depends substantially on protecting the healthy function of the fine branches of headwater streams (Zhang 2004). Forests significantly help protect these streams and preserve drinking water quality in watersheds by performing a number of ecosystem services: moderating stream flow and flooding, controlling surface runoff and erosion, buffering against pollutants, and preventing sedimentation and eutrophication of waterways (Zhang et al. 2004).

Hence, it is concluded that forest shelter belts preserve water quality by (1) slowing runoff, thus reducing floods, erosion, and sedimentation of rivers and reservoirs, and by (2) promoting infiltration of water into the soil, where it recharges groundwater and is purified by a number of biotic and abiotic processes.

References

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ 74:19–31

Archer JR, Marks MJ (1997) Control of nutrient losses to water from agriculture in Europe. Proc Fertil Soc 6(5):405–409

Chai SW, Pei XM, Zhang YL et al (2006) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conserv 20(6):191–194

Chen J, Shi L, Zhang A (2002) Controlling effects of forest belts on non-point source pollution of agricultural lands in Taihu Lake area, China. J For Res 13(3):213–216

Daniel TC, Sharpley AN, Lemunyou JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Environ Qual 27(1):251–257

Deckers B, Hermy M, Muys B (2004) Factors affecting plant species composition of hedgerows: relative importance and hierarchy. Acta Oecologica 26:23–37

Gao C (1999) Environmental management options practiced in Europe to mitigate agricultural nutrient pollution of ground and surface water. Agric Eco-Environ 51(2):50–53

Kleijn D, Verbeek M (2000) Factors affecting the species composition of arable field boundary vegetation. J Appl Ecol 37:256–266

Young RA (1989) A non-point source pollution model for evaluating agricultural watershed. J Soil Water Conserv 44(2):168–173

Zhang JF (2004) Agroforestry and its application in amelioration of saline soils in eastern China coastal region. For Stud China 6(2):27–33

Zhang JF, Jiang J (2010) Countermeasures to control agricultural non-point source pollution in Headwaters of Taihu Lake Basin. In: International conference proceedings on management and service science (MASS 2010)

Zhang JF, Shan Q (2009) Urban salinization and its ecological remediation principles. In: Proceedings of the 2009 international conference on engineering management and service sciences

Zhang WL, Wu SX, Ji HJ, et al (2004) Estimation of agricultural non-point source pollution in China and the alleviating strategies I. Estimation of agricultural non-point source pollution in China in early 21 century. China Sci Agric 37(7):1008–1017

Zhang JF, Fang MY, Li S (2007) Developing agroforestry in slopelands to combat non-point pollution in China. China For Sci Technol 6(4):67–72

Zhang JF, Jiang J, Zhang Z (2009) Discussion on role of forest to control agricultural non-point source pollution in Taihu Lake Basin-based on source-sink analysis. J Water Res Prot 1 (5):345–350

Chapter 7
Landscapes Change and Its Effect on Water Quality in Taihu Lake Watershed: A Case Study in Yixing City

Abstract In order to approach the spatiotemporal variation of non-point source pollution in Taihu Lake watershed, ten typical channels connected with Taihu Lake were selected in Yixing city. For these channels, "source–sink" landscape contrast index was calculated based on source–sink landscape theory in terms of some key factors concerned with the landscape contrast index such as distance, elevation, and slope, in addition to water sample collection and water quality analysis. The results showed that on the temporal dimension, source landscape increased significantly in Taihu Lake watershed while "source–sink" landscape contrast index decreased significantly during the term. On the spatial dimension, the smaller the landscape contrast index, the better the "sink" landscape interception to the non-point source pollution, and the higher the water quality, too. Thus, this study indicated that water quality has been improved since conducting shelter belts building around Taihu Lake, and they will intercept much more of the non-point source pollution with these trees growing.

Keywords Ecological public welfare forest · Non-point source pollution · Source–sink landscape · Source–sink landscape contrast index Taihu Lake watershed Water quality

Society and economy in the Taihu Lake watershed area always keeps on a rapid development based on the superior natural conditions. However, water eutrophication of the Taihu watershed gradually becomes dominant with the population growth and urbanization development, since reform and open policy are conducted. The water quality deteriorated from medium eutrophication to heavy eutrophication in some sections of the Lake, and pollution load drained into water also increased year by year (Wang et al. 2009; Jin et al. 1999; Liao et al. 2005). The serious diffuse pollution directly influenced the security of domestic water, restricted the functions of water, and hindered the sustainable development of society and economy in

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Taihu Lake watershed in recent years. Some studies (Zhang and Jiang 2010; Zhang et al. 2007, 2009) showed that the water pollution was the result of point source pollution combined with non-point source pollution, but the pollutants drained into the Taihu Lake over 50 % from the non-point source pollution. Formation, conversion, and mitigation of the non-point source pollution were intimately linked with spatial distribution of landscapes (Diebel et al. 2008; Tomer et al. 2009; Mattikalli and Richards 1996). The land use way also had a significantly influence on the non-point source pollution (Zhang et al. 2004; Liu et al. 2006; Zhang and Chen 2010). The appropriate landscape spatial configuration will be significant to reduce the discharge of nutrients and other pollutants and to improve the water quality of the Lake.

Landscape patterns and ecological processes interacted with each other. If established a reliable relationship between them, we can speculate the process characteristics by landscape pattern, further comprehend formation mechanism of the non-point source pollution, and deepen researches on landscape ecology (Chen et al. 2003a). Landscape pattern index has been taken into wide research topics since its initiation (Wu 2004; Li and Wu 2004; Fortin and Dale 2005), but it was linked to the actual processes of landscape ecology. In view of this case, Yixing segment of Taihu Lake watershed was selected in this study. This research was carried out to (1) analyze landscape characteristics and water quality of each channel; (2) quantify the interaction between the landscape pattern and the process of the non-point source pollution by introducing the "source–sink" landscape contrast index; (3) discuss the influence of the landscape pattern on output state of diffuse source pollution and water quality in this watershed; (4) and seek more appropriate landscape patterns. This study aimed to provide theoretical basis for controlling the diffuse source pollution in Taihu Lake watershed, modifying land use way, and constructing the ecological public welfare forests rationally.

7.1 Site Conditions of Experimental Area

Taihu Lake was located in the core area of Yangtze River delta, its total area of watershed was 3.69×10^4 km^2, and the area of existing water was 2338 km^2. Yixing was located in the west of Taihu Lake (119°31′–120°03′ E, 31°07′–31° 7′ N), a typical Chinese town of water. The geographical features in the south of the city were higher than those in the north: mostly hilly and mountains in the south and mainly plains in the north of the city. Yixing belongs to subtropical climate with four distinct seasons and adequate illumination. The average annual precipitation was 1264.1 mm. The average annual temperature was 16.5 °C. The annual daylight hour is 1726.1 h. The lake line of Taihu in this city was 43.5 km, from Fuzi Ridge of eastern Dingshu town, Xinzhuang to Baidu channel, where was the main production area of cash crops and grains in Yixing (Zhang et al. 2010a). There were 26 channels that are connected with the Lake, of which 14 ones managed by the province or state, such as Sharang, Shidu, Jiaodu, Shedu, and Hongdong and another 12 channels managed by the local at present. The ecological public welfare forest has been constructed for better growth for Taihu Lake in Yixing. The forest mainly distributed in the range of 250 m long at the west of Taihu bank and 30 m long of channel banks connected with the Lake within 3 km to the Lake. There are protective forests growing along lakeside roads, greening trees growing around village compounds, and shelter belts growing in farmlands (see Figs. 7.1, 7.2, 7.3, and 7.4). The lakeside protective forest was selected as the research region. The 3 km of radius was proposed to the buffer area from lakeshore to farmland. This study aimed at analyzing the non-point source pollution of channels connected with Taihu Lake in the buffer area.

Fig. 7.1 Agricultural production along the channel in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 7.2 Residents live along the channel in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 7.3 Farmlands shifted to forests along the channel in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 7.4 Trees are planted along the channel in Yixing (Photograph taken by Jianfeng Zhang)

7.2 Methods

7.2.1 Computation Method of "Source–Sink" Landscape Contrast Index

Chen et al. (2003b) brought up the theory of "source–sink" landscape and defined the concept of landscape contrast index. They firstly introduced the source and sink into air pollution. According to the theory, the landscapes promoting the ecological processes of pollution to positive development were defined as "source" landscapes. Conversely, the landscapes preventing or delaying the ecological processes of pollution were defined as "sink" landscapes. The "source–sink" landscape contrast index was the contrast index between the "source" landscape and the "sink" landscape in a certain ecological process. This index was analyzed based on Lorenz curve, data including differences among the "source" and "sink" landscapes with ones in monitoring point in this watershed, and calculating the accumulative percent area of each landscape changed with distance, elevation, and slope change.

The hierarchical approach method for the "source–sink" landscape contrast index proposed by Yue et al. (2007) also was employed in this study. This method replaced the sum of accumulative percent area between each landscape patch within equal interval and whole landscape with the irregular trilateral shaped area in

Lorenz curve. The distance of 250 and 500 m was regarded as the buffer intervals, and 6 intervals were designed to monitor the water quality. While the elevation and slopes were classified in view of the Digital Elevation Model (DEM) of the test area, The elevation was divided into 5 classes by 5-m interval and the slope was divided into 4 classes by 3-m interval. Accordingly, non-irrigated land, paddy field, construction land, industrial land, road, and orchard were classified as "source" landscape, whereas forested land, wetland, and water body were classified as "sink" landscape.

TN and TP in surface soil of all landscapes were analyzed to estimate the weight function of landscape type (the landscape contrast index), but the soil TN and TP cannot completely reflect the relative importance of the landscape pollution load; for example, in forested land, TN and TP contents are high because of litters accumulation, in this case the effect of pollutant intercepting by forest landscape not to be neglected. So the weight function of landscape types should be determined jointly by the soil nutrients and chemical fertilizers applied.

The contrast index of landscape spatial load was computed as follows:

$$\text{LCI} = \log\left(\sum_{i=1}^{m} S_i \times W_i \times P_{tci} / \sum_{j=1}^{n} S_j \times W_j \times P_{tji}\right)$$

where LCI (landscape contrast index) represents the accumulative contrast index of landscape spatial load within a certain range at the watershed scale, including contrast elevation (LCI_CE), contrast slope (LCI_CS), and contrast distance (LCI_CD); m and n represent the quantity of the "source" landscape and "sink" landscape, respectively; S_i and S_j are the sum of accumulative percent areas of the "source" landscape and "sink" landscape, respectively; W_i and W_j are the contrast weights of the "source" landscape and "sink" landscape for forming and reducing the non-point source pollution, respectively; and P_{tci} and P_{tcj} represent the proportions that the area of ith "source" landscape and jth "sink" landscape accounted for the area of total area of whole landscape, respectively. The contrast indexes of landscape spatial load were calculated by above formula in the test area of 2004 and 2010.

7.2.2 Field Sampling

The channels of Dagang, Dingkua, Miaodu, Zhangze, Dapu, Hongdong, Shedu, Shidu, and Shatang, connected with the Lake, were selected as test plots, based on the spatial distribution and geographical distribution of landscape patterns in Yixing section of Taihu watershed (see Table 7.1). The monitoring sites of water quality were laid in the mouth of channels to the Lake. Water samples were collected in August, September, and October of 2010, 500 mL of each for analyzing water quality, and those samples were sealed and analyzed in the same day afternoon by

Table 7.1 Landscape characteristics of Taihu Lake watershed in different years

Year		Landscape types	Area (km^2)	Percentage (%)	"Source–sink" landscape contrast index
2010	"Sink" landscapes	Waters	5.3	5.25	0.04
		Secondary forest	4.5	4.46	0.22
		Ecological public welfare forest	37.3	36.93	0.14
		Wetland	4.5	4.46	0.09
	"Source" landscapes	Building site	16	15.84	0.11
		Dry land	22	21.78	0.07
		Industrial land	1.5	1.48	0.15
		Orchard	1.6	1.58	0.03
		Paddy field	7	6.93	0.11
		Road	1.3	1.29	0.04
2004	"Sink" landscapes	Waters	12.8	13.0	0.03
		Secondary forest	12.2	12.02	0.28
	"Source" landscapes	Building site	10.3	10.15	0.16
		Industrial land	1.4	1.38	0.19
		Paddy field	34.7	34.19	0.16
		Road	3.4	3.34	0.07
		Non-irrigated land	26.2	25.81	0.11

Yixing Water Quality Monitoring Station, which belonged to Chinese Academy of Environmental Sciences. TN was oxidized by K_2SO_4 and was analyzed by ultraviolet spectrophotometry. TP was analyzed by ion chromatography. NH_3–N was analyzed by Nessler's reagent colorimetric method. COD_{Mn} was analyzed by the acid process (State Environment Protection Adminstration of water and wastewater monitoring and analysis methods Editorial Board 2002).

The soil samples (0–10 cm depth) were collected with the method of plum blossom, i.e., five replications in each landscape type (see Figs. 7.5 and 7.6). But the five replications were mixed evenly in one sample when analyzed. The TN and TP of all samples were determined by Key Laboratory of Institutes of Subtropical Forestry, Chinese Academy of Forestry, after air-dried, according to the national standard of China (National Agricultural Technology Extension Service 2005).

7.2.3 Statistical Analysis

Data of water quality of 10 channels were analyzed by the origin7.5. And data of water quality in Lanshanzui monitoring point were collected from Annual Report on Water Quality in Yixing of 2004 and 2010, and acted as describing data.

Fig. 7.5 Soil samples are collected in forested land (Photograph taken by Ying Wang)

Fig. 7.6 Soil samples are collected in farmland (Photograph taken by Ying Wang)

7.3 Results

7.3.1 Landscape Contrast Index

The landscape contrast indexes of 2004 and 2010 were shown in Fig. 7.7. If the contrast index between the "source" landscape and "sink" landscape was zero, it indicated that the "source" landscape and "sink" landscape were distributed evenly. If the contrast index between the "source" landscape and "sink" landscape was greater than zero, it indicated that the contribution of the "source" landscape on the non-point source pollution was larger than that of the "sink" landscape. If the contrast index between the "source" landscape and "sink" landscape was smaller than zero, it indicated that the contribution of the "source" landscape on the non-point source pollution was smaller than that of the "sink" landscape. The distance, elevation, and slope showed different influence on the index. The nearer the distance of the "source" landscape relative to the monitoring point was, the greater its contribution on the non-point source pollution was; the farther the distance of the "source" landscape relative to the monitoring point was, the less its contribution on the non-point source pollution was. The lower the elevation of the "source" landscape relative to the monitoring point was, the greater its contribution on the non-point source pollution was; the higher the elevation of the "source" landscape relative to the monitoring point was, the less its contribution on the non-point source pollution was. But the smaller the elevation of the "source" landscape relative to the monitoring point was, the smaller its contribution on the non-point source pollution was; the greater the elevation of the "source" landscape relative to the monitoring point was, the greater its contribution on the non-point source pollution was. The contribution of the "sink" landscape on the pollution in 2010 was significantly larger than that of the "source" landscape. It can be explained that many ecological public welfare forests were planted by the government of Yixing in the coast of Taihu Lake, since 2002, especially after massive outbreak of cyanophyta in 2007 (Zhang et al. 2010a). The ecological construction was not only to return the grain plots to forests, also transform fishpond to wetlands and transform paddy field to non-irrigation lands in the coast of Taihu Lake. These measures increased the "sink" landscape or decreased the "source" landscape, which was reduced significantly the non-point source pollution in the test area.

The landscape contrast index based on the relative distance was shown in Fig. 7.7a, b. LCE_RD was gradually increased with the increasing of distance (Fig. 7.7). It implied that pollutant output of the non-point source pollution also was increased with the increasing of distance. The contribution of the "sink" landscape in 2010 was significantly larger than that in 2004 within the range of 0–2.5-km buffer area. Because the first stage of construction of the ecological public welfare forest in the coast of Taihu Lake had been completed in 2007, the forest was mainly concentrated in the range of 250 m at the west of Taihu bank and 30 m of channel banks within 3 km to the Lake. Clearly, the nearer the distance away from the monitoring point was, the greater the influence of forest was. So the forest in the

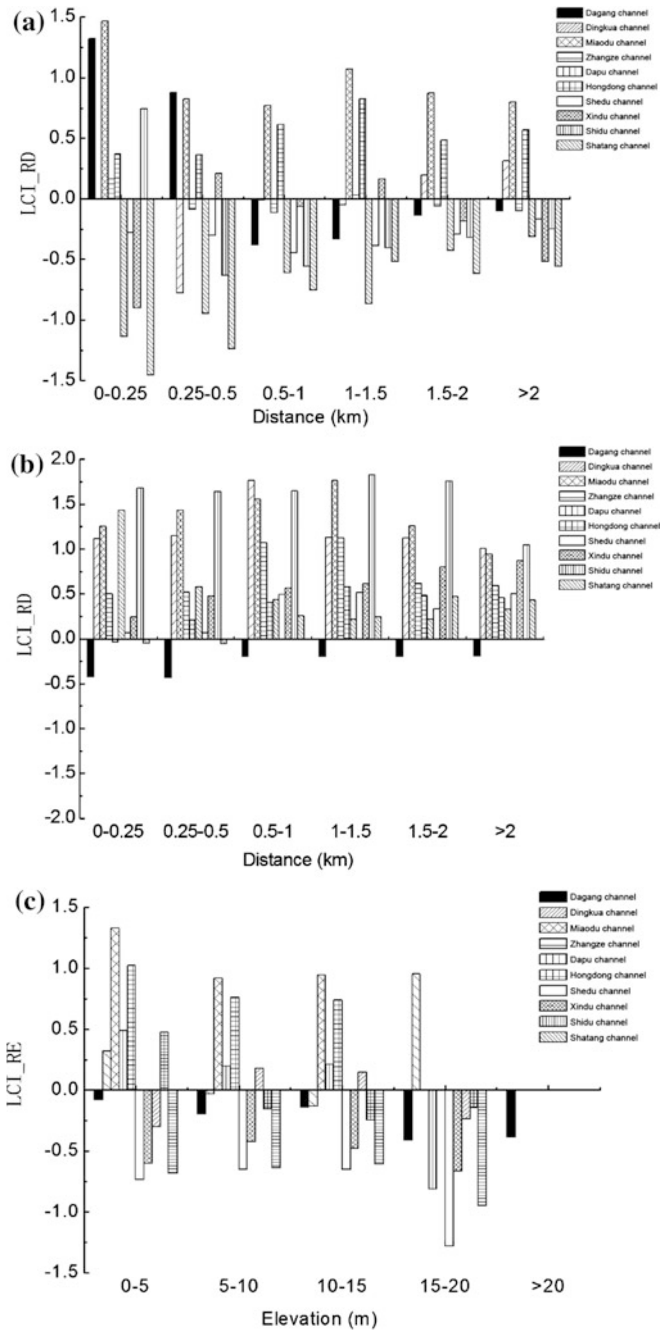

Fig. 7.7 LCI of Taihu Lake watershed for different channels in different years (**a**, **c**, **e**—landscape contrast index in 2010; **b d**, **f**—landscape contrast index in 2004)

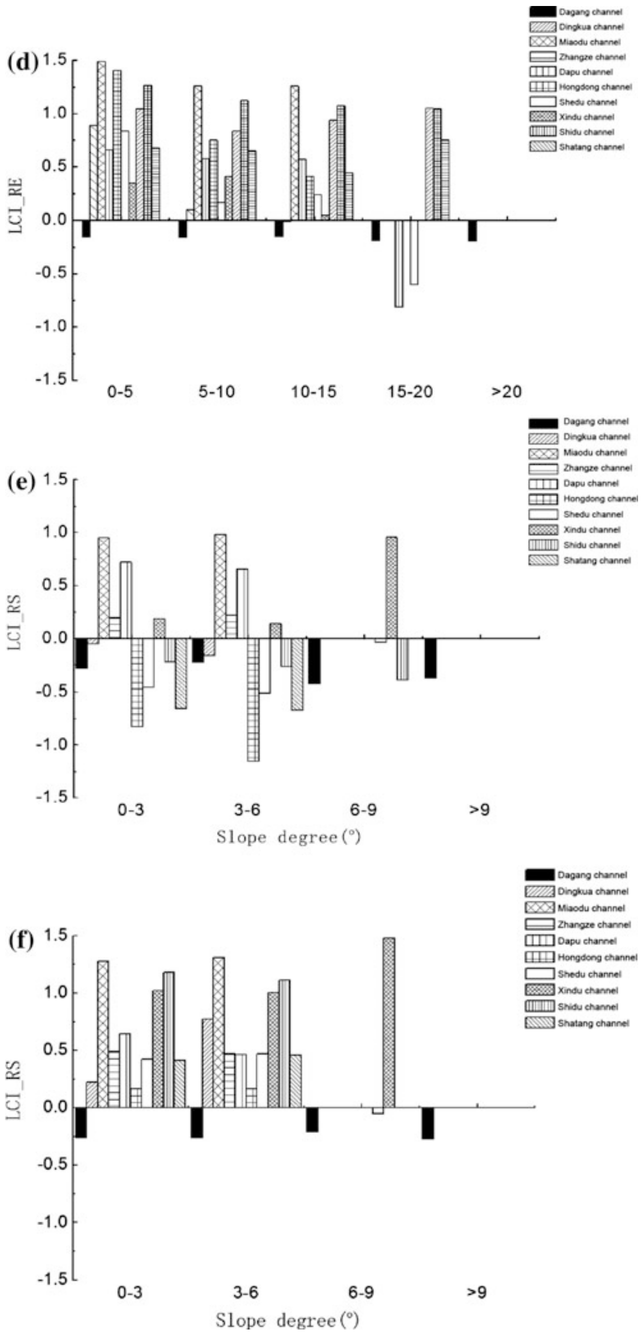

Fig. 7.7 (continued)

range of 0–2.5 km of buffer area can play an important role to intercept pollutants. The Miaodu channel was a new Ecological and Agricultural Sightseeing Park in Taihu Lake region. Its landscape types mainly were arable lands and orchard, so its contribution of the "sink" landscape was greater. Even if the area of the "source" landscape was greater than that of the "sink" landscape in Dagang channel, where original secondary forest took up a larger area of this region. The forest had superior absorption and migration function on pollutants, so that the relative important index was greater when calculated the "source–sink" landscape contrast index, and the relative importance index reduced quickly when the distance increased.

The landscape contrast index based on the relative elevation was shown in Fig. 7.7c, d. Yixing was lower in elevation and under the topography of "high in the south, low in the north," so that within the range of 15–20 m of the elevation, the Miaodu port had no "source" landscape and "sink" landscape and the Zhangze channel (Fig. 7.7c), Dingkua channel, Dapu channel, and Shedu (Fig. 7.7d) channel only had the "sink" landscape. When the elevation of channel was greater than 20 m, there were no significant distinctions between all channels, outside the Dagang channel. The LCI_RE reduced with the decreasing of the elevation, which indicated that pollutants in the landscape also reduced with the decreasing elevation. The landscape contrast index decreased with increasing elevation, which implied that the contribution of the "sink" landscape increased with increasing elevation. One can draw a conclusion that there was a positive correlation between elevation and water quality that pollution level of water reduced with increasing elevation.

The landscape contrast index based on the relative slope was shown in Fig. 7.7e, f. The study area was mostly flat with few slopes. The LCI_RS of Dagang channel, Shedu channel, Xindu channel, and Shidu channel can be calculated, but the other channels cannot, when the slope was 3°–9°. Only Dagang channel had the LCI_RS, when the slope was greater than 9°. Here, all of those indicated that the slope did not have many influences on water pollution in the area.

7.3.2 *Change of Water Quality*

7.3.2.1 Water Quality Change in Different Years

Water quality in 2004 and 2010 in the Lanshanzui monitoring point of Yixing was shown in Fig. 7.8. pH increased from 7.5 in 2004 to 7.98 in 2010. DO fell slightly from 8.1 in 2004 to 7.96 in 2010, with 17.525 of drop. Permanganate concentration increased largely from 3.91 mg L^{-1} in 2004 to 5.48 mg L^{-1} in 2010. NH_4^+ occurred the biggest change, from 0.83 mg L^{-1} in 2004 to 0.49 mg L^{-1} in 2010. The NH_4^+ was an important indicator of water quality. Its reduction showed that the control of non-point source pollution had an effect but cannot fully improve the water quality. The water pollution in 2004 was better than that in 2010, which

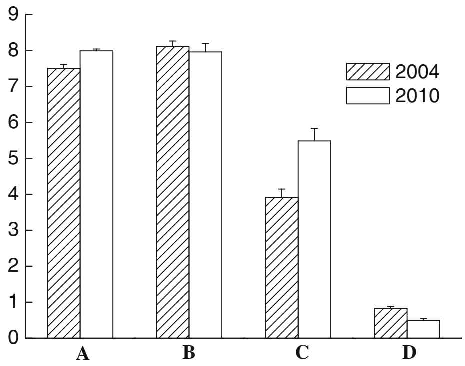

Fig. 7.8 Water quality change at Taihu Lake watershed in different years (*A*—pH; *B*—DO (mg L^{-1}); *C*—COD_{Mn} (mg L^{-1}); *D*—NH_3–N (mg L^{-1}))

indicated the "source–sink" landscape contrast index decreased, the "sink" landscape increased and water pollution relieved from 2004 to 2010.

7.3.2.2 Spatial Distribution of Water Quality

The NH_4^+ was greater between Shatang channel (1.25 mg L^{-1}) and Dapu channel (6.9 mg L^{-1}), and there were no obvious differences between other channels (Fig. 7.8). Riparian vegetation had a significant effect on improving water quality (Dillaha et al. 1989; Lin et al. 2004; Gassman et al. 2006; Zeng et al. 2010). So the Shatang channel with many forest had a greater capacity for intercepting and migrating the non-point source pollution than the Dapu channel as an industry area. And there were differences between channels for other indicators of water quality. But the differences of water quality of all channels were small. It can be explained that the landscapes within 250 m of buffer area at the west of Taihu bank were the ecological forest and wetland, and these "sink" landscapes can intercept many pollutants drained into Taihu Lake. Furthermore, the "source–sink" landscape contrast index still influenced the water quality for the greater buffer area.

The area of the ecological public welfare forest in the Shatang channel was the biggest compared with that of other channels. And the forest in Shatang channel grew exceptionally well. The "source–sink" landscape contrast index of the Shatang channel was always smaller in 2010 (Fig. 7.7). And its concentration of water pollutant was lower compared with that of other channels (Fig. 7.8), especially for NH_3 + and TN. While NH_3^+ and TN were 1.25 and 2.75 mg L^{-1}, respectively, the greatest value of NH_3^+ and TN in other channels was 6.9 and 4.32 mg L^{-1}, respectively. Even if the "source–sink" landscape contrast index of Dapu channel was also smaller (Fig. 7.7), the water quality of Dapu channel suffered from severe pollution (Fig. 7.8). The concentration of NH_3^+ was 6.9 mg L^{-1} which was the greatest value in all channels. The concentration of TN, COD_{Mn} and TP was 3.30, 7.04, and 0.25 mg L^{-1}, respectively, because Dapu channel was adjacent to Dapu industry region. Although the area of Dapu industry region was not large, it discharged a large volume of pollutants. So relative significance of the “source” landscape was larger and showed a higher “source–sink” landscape contrast index in Dapu channel. Within 0–500 m of Dagang channel had a higher “source–sink” landscape contrast index, but the falling rate of the index was greater than 500 m. There were many wild woody plants closed to Dagang channel that can efficiently absorb and migrate pollutants. NH_3^+, TN, TP, and COD_{Mn} showed a lower concentration, namely 2.45, 4.32, 6.72, and 0.21 mg L^{-1}, respectively. All of the results indicated that the “source–sink” landscape contrast index was intimately linked with landscape types. And many previous researches (Liu et al. 2009; Chen et al. 2003a; Li et al. 2010; Zhang et al. 2010b) recognized the results as well.

7.4 Discussion and Conclusions

According to land use change in Yixing segment of Taihu Lake watershed, this research was carried out to calculate the “source–sink” landscape contrast index and analyzed the non-point source pollution combined with the corresponding water quality data and ecological processes, within the 3 km of buffer area. The main conclusions have been summarized as follows:

1. The variation tendency of the “source–sink” landscape contrast index was roughly identical to temporal and spatial variation of the water quality, which stated that the index could clearly reflect the formation and migration of the non-point source pollution.
2. The “source–sink” landscape contrast index had close relationships with the landscape area and landscape type. Although some “source” landscapes and “sink” landscapes had smaller area, their influences on the non-point source pollution were greater and their relative significances and their contributions on the index were greater. These characteristics were roughly identical to the water quality, such as in Dapu and Dagang channels.
3. Reducing the “source–sink” landscape contrast index could decreased the pollutants drained into the water body of the Taihu Lake watershed and raised the relative significance index of the “sink” landscape, thereby improving the absorption and migration functions of landscapes. Decreasing “source” landscape and increasing “sink” landscape all could reduce “source–sink” landscape contrast index, which was an effective method to improve the non-point source pollution.
4. Riparian vegetation had a significant effect on improving water quality. It meant vegetated areas increasing could enlarge “sink” landscape area and gradually prevent the non-point source pollution. This indicated that constructing the lakeshore protective forest could efficiently intercept the non-point source pollution in the coast of Taihu Lake, especially within 250 m of the banks. And the function of the lakeshore protective forest on non-point source pollution reduction would become much more apparent as time went on (see Figs. 7.9 and 7.10).

Fig. 7.9 Water quality is improved by forest buffers in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 7.10 Water quality gets better with forests growing in Yixing (Photograph taken by Jianfeng Zhang)

The ecological public welfare forest engineering had achieved remarkable progress in the Taihu watershed in recent years. It is important to point out that there was a quite significant of the “source–sink” landscape contrast index between 2004 and 2010, but their water quality had no obvious improvement, which may be related to the sampling time and region of water. When the water samples were collected in rainy season, large amounts of sediments flowed into the river, resulting in the deterioration of water quality. On the other hand, the stand structure and functions of forest all were not sound and perfect because the construction of the ecological public welfare forest just started in 2007. Naturally, the forests cannot exert more functions on pollutants interception and migration compared with the natural secondary forests. So it is important to strengthen the construction and management of the lakeshore protective forests to improve its ecological functions, to intercept and to migrate the pollutants, furtherly to protect the environment, and to improve the water quality.

References

Chen LD, Fu BJ, Xu JY et al (2003a) Location-weighted landscape contrast index: a scale independent approach for landscape pattern evaluation based on “Source-Sink” ecological processes. Acta Ecol Sin 23(11):2406–2413

Chen LD, Qiu J, Zhang SR et al (2003b) Tempo-spatial variation of non-point source pollutants in a complex landscape. Environ Sci 24(3):85–90

Diebel MW, Maxted JT, Nowak PJ et al (2008) Landscape planning for agricultural nonpoint source pollution reduction I: a geographical allocation framework. Environ Manage 42(5): 789–802

Dillaha TA, Reneau RB, Mostaghimi S et al (1989) Vegetative filter strips for agricultural nonpoint source pollution control. T Am Soc Agri Eng 32:513–519

Fortin MJ, Dale MRT (2005) Spatial analysis: a guide for ecologists. Cambridge University Press, Cambridge

Gassman PW, Osei E, Slaeh A et al (2006) Alternative practices for sediment and nutrient loss livestock farms in northeast Iowa. Agric Ecosyst Environ 117:35–144

Jin XC, Ye C, Yan CZ et al (1999) Comprehensive treatment plan for key-polluted regions of Lake Taihu. Res Environ Sci 12(5):1–5

Li H, Wu J (2004) Use and misuse of landscape indices. Landscape Ecol 19:389–399

Li ZF, Liu HY, Li HP et al (2010) Impacts on nutrient export by landscape heterogeneity based on sub-watershed. Environ Sci 31(9):2029–2035

Liao WG, Peng J, Luo HH (2005) Some consideration on water pollution prevention strategy for Taihu lake. J China Inst Water Res Hydropower Res 3(1):6–10

Lin YF, Lin CY, Chou WC et al (2004) Modeling of riparian vegetated buffer stirp width and placement: a case study in Shei Pa National Park. Taiwan Ecol Eng 23:327–339

Liu RM, Yang ZF, Ding XW et al (2006) Effect of land use/cover change on pollution load of non-point source in upper reach of Yantze river basin. Environ Sci 27(12):2407–2414

Liu F, Shen ZY, Liu RM (2009) The agricultural non-point sources pollution in the upper reaches of the Yangtze River based on source-sink ecological process. Acta Ecol Sin 29(6):3271–3277

Mattikalli NM, Richards KS (1996) Estimation of surface water quality changes in response to land use change: application of the export coefficient model using remote sensing and geographical information system. J Environ Manage 48:263–282

National Agricultural Technology Extension Service (2005) National technical specifications soil testing and fertilizer

State Environment Protection Adminstration of water and wastewater monitoring and analysis methods Editorial Board (2002) Water and wastewater monitoring analysis method, 4th edn. China Environmental Science Press, Beijing

Tomer MD, Dosskey MG, Burkart MR et al (2009) Methods to prioritize placement of riparian buffers for improved water quality. Agrofor Syst 75(1):17–25

Wang XZ, Wang AL, Yin WQ et al (2009) Application of agricultural non-point source pollution potential index in typical area of Taihu: a case study in Kunshan city. J Agro-Environ Sci 28(9):1874–1879

Wu J (2004) Effects of changing scale on landscape pattern analysis: scaling relations. Landscape Ecol 19:125–138

Yue J, Wang YL, Li GC et al (2007) The influence of landscape spatial difference on quality at differing scales: a case study of Xili reservoir watershed in Shenzhen city. Acta Ecol Sin 27(12):5271–5281

Zeng LX, Huang ZL, Xiao WF et al (2010) Function, design and management of riparian vegetation buffer strips. Sci Silvae Sini 46(2):128–133

Zhang HJ, Chen F (2010) Non-point pollution statistics and control measures in Taihu Basin. Water Res Prot 26(3):87–90

Zhang JF, Jiang JM (2010) Countermeasures to control agricultural non-point source pollution in headwaters of Taihu Lake basen. In: International Conference Proceedings of the management and service science (MASS 2010)

Zhang RB, Yao Q, Ji Y (2004) Research on non-point pollutant losing law of a typical small valley in Taihu lake basin. Yantze River 35(10):38–40

Zhang JF, Fang MY, Li S et al (2007) Developing agroforestry in slopelands to combat non-point pollution in China. Chin Sci Tech 6(4):67–72

Zhang JF, Jiang JM, Zhang ZJ (2009) Discussion on role of forest to control agricultural non-point source pollution in Taihu Lake basin-based on source-sink analysis. J Water Res Prot 1(5):345–350

Zhang DW, Li YF, Sun X et al (2010a) Relationship between landscape patterns an river water quality in Wujinggang region, Taihu lake watershed. Environ Sci 31(8):1775–1783

Zhang JF, Sheng HQ, Gu CL et al (2010b) Discussion on the construction of ecological public welfare forests in Taihu lake basin at Yixing. J Anhui Agric Sci 38(18):9720–9721, 9749

Chapter 8
Ecological Public Welfare Forests Construction in Yixing City

Abstract At present, non-point source pollution is becoming more and more serious in the country with population growth and socioeconomic development. While forest coverage is decreased there, when heavy raining happens, soil erosion gets worsening. There are 3.67 million km^2 lands being in erosion, accounted for 38.2 % of the total in the country. In this case, much more nutrients enter rivers and lakes that result in eutrophication. This chapter introduced the functions and planning principles of ecological public welfare forests construction in Taihu basin based on the current state of socioeconomic development and requirement of eco-environment by urbanization in the country. Some problems and suggestions in the construction of ecological public welfare forests were discussed in Taihu basin. In particular the construction of water source protection forest was stressed in view of the crucial state of water environment in the region. Moreover, the maintenance measures of ecological public welfare forests also were probed.

Keywords Ecological public welfare forest · Water source protection forest · Ecological effect · Construction · Taihu basin · Yixing · Water environment

With the sustained growth of population in China, in addition to the rapid development of industrialization, the demand on forest resources is getting more and more (Gu et al. 1995). However, due to insufficient areas and unreasonable structure, the comprehensive effect of forest failed to fully play in Taihu Lake basin. In the region generally speaking topography is flat and low-lying, rivers and lakes intertwined, dotted with Taihu Lake in the central depression. It is well known that Taihu Lake is the third largest freshwater lake in the country. In Taihu basin, it provides advantages for social development owing to its excellent geographical location and natural conditions. The fact is that it takes about 0.4 % of the country's land area and 3 % of the total population, however, created annually about 11.6 % of national GDP and 22.1 % of revenue. Hence, here is the degree of industrialization and urbanization the highest (ca 73 %) and is one of the most developed. Correspondingly, it is one of the most dynamic regions for investment growth, economy expansion, and social development, too. Obviously here to a certain

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extent plays a decisive role in the national economic and social development. For long time, water security is paid a great attention in the watershed. In particular after Wuxi water pollution incident occurred in Taihu Lake in the summer of 2007, more and more people much clearly understand and recognize the harm of agricultural non-point source pollution. Consequently, ecological public welfare forest construction becomes the urgent issue (Xue and Chen 2000).

8.1 Introduction

Ecological public welfare forests or non-commercial forests are important ecological niche, play an important role under fragile ecological conditions on land ecological safety, biodiversity conservation, and economic and social sustainable development. Usually, it aims to provide public welfare, social products, or services as the main purpose when they are to be built. In accordance with the rule of forest protection, management and exploitation of these forests must follow relevant provisions of the state and the standard (Yu 1999; Jiao et al. 2000). Hence facing the current state of environment deteriorating, it is necessary to pay much more attention on ecological construction, mainly focusing on establishing a complete ecological protective forest system in China, which seems to be the main task of forest construction in twenty-first century (Zhang and Qin 2007; Zhang and Sun 2005).

With the rapid development of socio-economy and population growth in the country, the process of urbanization is accelerating, more and more cities burdens are increasing, accordingly, the environmental pressure is getting greater (Yang et al. 2003). It has approved that forests have the functions on climate regulation, soil and water conservation, oxygen production, CO_2 absorption, and so forth. Therefore, the construction of a large area of ecological forest is an important part of ecological construction and has a very important significance (Zhong et al. 1999; Xue et al. 2001a, b). In Taihu Lake basin, it is especially crucial by planting trees to reduce surface runoff and prevent water pollution. And at the same time, there are studies shown that NPS pollution was greatly reduced in Taihu Lake by carrying out Taihu forestry ecological engineering construction and wetland restoration or construction, thereby load of nitrogen and phosphorus in the Lake fell (Chai et al. 2006; Ding et al. 2010). According to the research, one shelterbelt with 50 m width between the farmland and rivers would reduce nitrogen and phosphorus draining into rivers 80 and 89 % of the total (Chen et al. 2002a, b). Thus, forestry ecological engineering construction is the main body of ecological construction, and it not only can conserve drinking water sources and improve highly water quality, but also can prevent soil from erosion, reducing sediments into the Lake (Yong and Chen 2002). Moreover, it can effectively filter and absorb nitrogen and phosphorus, prevent Taihu Lake eutrophication (Zhang et al. 2007). How to build a fine ecological public welfare forest in accordance with local conditions, to better play its ecological functions, is worthy of further probing.

8.2 Natural and Social Economic Status in Yixing

8.2.1 Natural Geography Conditions

Yixing lies at the geometric center of the three cities of Shanghai, Nanjing, and Hangzhou, located at 119°31′–120°03′E, 31°07′–31°7′N, a total area of 2038 km^2, with a land area of 1582 km^2, of which 456.7 km^2 around Taihu Lake. The geographic characteristics are as follows: in the south are more mountains and hilly regions and in the north mostly are plain polder areas. Yixing is located in the subtropical monsoon climate zone, where there is a clear seasonal change , ample sunshine, a long frost-free period, the average annual temperature of 16.5 °C, and accumulated sunshine time of 1761.1 h, with annual average precipitation of 1264.1 mm. There are totally 3699 channels managed by different levels of city, town, and village in Yixing, where total length is 3242 km. River density is about 2.27 km^{-2}, including four water systems, called Nanxi river, Taogetai river, Li river, and Huangchuan river. These channels play an important role on controlling flood, performing irrigation, supplying water to urban and rural areas, conducting transportation and shipping, etc.

There are lots of ponds, lakes, and channels, which form river networks in plain polder areas of Yixing, of which major lakes are Taihu Lake, Gehu Lake, Tuanjiu Lake, Dongjiu Lake, and Xijiu Lake. The total coast length of the Lake in Yixing is 43.5 km. Formerly, there were 61 rivers and channels connected with Taihu Lake, of which some were cut off or filled up in order to prevent flood or control pollution. Nowadays, a total of 26 rivers and channels exist linked into the Lake.

8.2.2 Social and Economic State

Yixing city consists of 17 towns and townships; besides, there are 1 national-level industrial park, 1 provincial-level economic development zone, 3 state-owned forest farms for plantation and tea production, 244 administrative villages, and the total population was 1,060,500, of which the urban population was 354,000 in 2007. Yixing is famous for pottery in China; moreover, it is an eco-tourism city, industrial and commercial city in the Yangtze River Delta, and at the junction of Zhejiang and Anhui Provinces. Yixing city is located in the famous Taihu scenic area, famous for mountains, river networks, beautiful bamboo stands, and abundant resources, known as “the ancient capital of pottery, an oasis of tea, great bamboo forest” in the country. In recent years, with the development of economy and the improvement of people’s living standard, the awareness of environmental protection continues to strengthen, all levels of governments continue to increase investment, accelerate forestry development based on use of rich natural conditions endowed by nature, promote farmer’s incomes growing, and improve the ecological environment.

8.2.3 Forest Resources Totally

The city's forested land area is 53,500 ha, including woodland and forests 49,400 ha accounting for 92.3 % of the total area of forested land; for forests, pine stands, fir stands, and broad-leaved trees dominated mixed stands are 15333.3 ha, in addition to 12,000 ha of bamboo plantation. The city's forest coverage rate reaches 29 %, stock volume is 338,000 m^3, including total 33,630,000 bamboo stock, farmland shelterbelts, and protective forests 51,866.7 ha, and trees growing in the four sides cover totally 5,825,000, and its stock volume is 203,000 m^3. Yixing has superior natural conditions and rich plant resources and is the area of most vegetation kinds and complex composition in Jiangsu Province. Here there do exist vascular plants of about 183 families and 1236 species, including 159 families and 1187 species of seed plants. The dominated natural vegetation type is a typical northern subtropical evergreen broad-leaved forest and evergreen and deciduous broad-leaved mixed forest. The main tree species are *Cyclobalanopsis glauca*, *Castanopsis sclerophylla*, *Phonebe* sp., oak, elm, oil, beech, fir, masson pine, lodgepole pine, slash pine, bamboo, *Phyllostachys*, ginkgo, tea, chestnut, pear, plum, etc. There is a provincial-level Longchi plants natural reserve and Yixing National Forest Park.

8.2.4 Forests Distribution Along Taihu Lake

In Yixing, around Taihu Lake area including Zhoutie Town, Xinjie Town, Dingshu Town, Fangqiao Town, and Wanshi Town, there are total five towns and 71 administrative villages covering an area of 422 km^2, the length 43 km around the Lake coast from north to south. The existing ecological public welfare forest around Taihu Lake in Yixing is 28,000 Mu (1 Mu is equal to 1/15 ha), 110 million Yuan invested to complete it, jointly funded by the city and town (street) two levels of government, and by renting lands from villagers for the construction of forests. In order to achieve community participation management, the local administrative village owns the forest property rights. In accordance with the principle "who has who manage," these trees are managed uniformly by the administrative villages.

These ecological public welfare forests are mainly concentrated in the following three areas.

1. Along the Taihu Lake west embankment, within the width 250 m of bank side, an area of 8000 Mu (see Fig. 8.1).
2. Along the 14 rivers linked into the Lake, within the width 50 m on both banksides and length 10 km, the area is 10,000 Mu (see Figs. 8.2 and 8.3).
3. Shelterbelts along villages and roads and farmland protective forests, an area of 7000 Mu (see Figs. 8.4 and 8.5).

Fig. 8.1 Forests grow along Taihu Lake banks (Photograph taken by Jianfeng Zhang)

Fig. 8.2 Forests grow along the channel linked into Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 8.3 Forests distribute along the river linked into Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 8.4 Shelterbelts distribute in farmlands (Photograph taken by Jianfeng Zhang)

Fig. 8.5 Forests grow along roads (Photograph taken by Jianfeng Zhang)

The construction of the Taihu ecological public welfare forests is divided into two main stages:

1. The first stage was from 2002 to 2005, the construction area 15,000 Mu, mainly concentrated in the Taihu Lake west embankment, within the width 250 m of bankside, and along the 14 rivers linked into the Lake, within the width 30 m on both sides and length 3 km, as well as shelterbelts along villages and on both sides of the roads, farmlands, too. The afforestation tree species mainly are poplar, metasequoia, and *Ikesugi tamesuke*.
2. The second stage was in late 2007 to spring 2008, the area 13,000 Mu, mainly concentrated in the area offshore 200 m west embankment for fishing, farmland area, and on both banksides of 50 m width of main rivers connected with the Lake with 10 km length, mixed forests were built for water conservation.

Through these projects, the forest coverage rate in this region is increased and polluted water is gradually recovered.

8.3 Ecological Public Welfare Forests Construction

Currently, the main problem of water environment was eutrophication in northern Taihu Lake, which showed deterioration of water quality and green-blue algae bloom; for eastern Taihu Lake was degradation of marsh and aquatic ecosystem. An important part of the comprehensive management of water environment is the construction of ecological public welfare forests aiming at water conservation (Su et al. 1999).

Water conservation forest is a special forest built around the water sources and soil and water conservation areas, which plays the functions of intercepting rainwater, increasing infiltration and soil moisture, decreasing surface evaporation, moderating surface runoff, and controlling soil erosion (Yu et al. 2002; Chen et al. 2002a, b). And through the comprehensive effect of these functions, regulating efficiency of water conservation by this forest is strengthened and sustained. According to the determination, when forest area reached 50,000 Mu and the canopy density more than 0.6, the water it conserved would be equivalent to a 1,000,000 m^3 of small reservoir. The water stream was perennially apt to be uniform and stable in this forest, but in the low forest coverage area often flooding caused during the rainy season, and in dry season rivers were easy to suffer shallow flow. The forest can effectively prevent the water resources from the physical, chemical, and biological pollution. Meanwhile, forest soils have water filtering effect and can purify water, improve water quality. Moreover bacteria number of water when passing through the forest is less than that through the farmland 2–2.5 times, however, is lower from 10 to 23 times than that through the pasture.

With the rapid development of economy and civilization, many people have more and more demand on the ecological environment construction, expect to achieve scientific, culture, esthetics, ethics, and other aspects of health value through the public welfare forest construction, by which provides a more comfortable, beautiful production, living environment (Xuan et al. 1999; Xue et al. 2001a, b). Therefore, in order to protect the ecological environment, it is necessary to speed up the construction of water conservation forest, improve the quality of water conservation forest, giving full play to water conservation, soil conservation, water purification, and other functions. Therefore, realizing the goal “green lands, clean flows” is currently an urgent and important task for the Taihu Basin forest construction work, also is the issue related to the rural social stability and water security for population of about 40,000,000.

Landscaping and greening of the environment should be the main project of Taihu Lake water conservation forest reconstruction, so as to achieve water conservation, soil conservation, air purification, regulating climate, and developing forest eco-tourism. The construction of ecological public welfare forests should follow the subsequent principles:

1. Adhere to the principle of beautifying the green environment and developing economy integration. The construction of water conservation forest as an important part of socioeconomic development, must be in accordance with the

overall goal of whole social and economic development, conforms with overall planning and implementation of synchronization requirements, consequently brings about the unity of ecological benefits, social benefits, and economic benefits. The water conservation forest building must match the processing industry and market development organically, conducting under synchronized planning and simultaneous construction. That is important to give full play to "the three major benefits of forestry".

2. Adhere to the principle of appropriate trees for suited sites and actual practice as well as the effectiveness. Focusing on the on the spot investigation, we perform afforestation when it is appropriate or just replant under certain case, which demands the design is scientific and reasonable and the measures have to be feasible and appropriate, so as to ensure the certain survival rate of afforestation, further more improve the quality of afforestation, increase forest tree species composition and modify stand structure, strengthen the management force, finally heighten the construction of water conservation forest gradually to a better level.
3. Insist on the principle of reasonable layout, concentrating on focal point and step-by-step implementation. Water conservation forest and the ecological system construction planning should be combined with regional overall planning and rational distribution. We strive to complete the construction tasks in five years step by step, firstly focusing on key area of water sources, and then gradually extending to the others.

8.4 Works Have Done

There were 85,000 Mu of woodland newly added in Yixing from the beginning of 2009 to the end of 2010, of which 60,000 Mu was landscape protective forest in Taihu Lake riparian zone, in addition to economic forest (including energy forest) 20,000 Mu, as well 5000 Mu of timber forest. Therefore, the forest coverage rate increased 2.78 % points, run up to 31.38 %; the village green coverage rate reached 38 % totally. The detailed construction state of protective forests in Yixing was as follows:

1. Along the coast of Taihu Lake within 200 m width: An area of 12,000 Mu plantations had been completed along the Taihu Lake 40 km long and 200 m wide. The native deciduous tree species are dominant for water conservation forests. Mainly they included the following species: *Ginkgo biloba, Camptotheca acuminata, Pterocarya stenoptera, Celtis sinensis, Ulmus pumila, Ailanthus altissima, Pistacia chinensis, Melia azedarach, Koelreuteria paniculata, Sophora japonica, Firmiana simplex, Sapium sebiferum, Metasequoia glyptostroboides, Taxodium ascendens, Taxodium distichum, Catalpa bungei, Aesculus chinensis, and Albizia julibrissin,* and other evergreen species such as *Ilex chinensis, Elaeocarpus decipiens, Ligustrum lucidum, Taxus chinensis, Osmanthus*

fragrans, Viburnum odoratissimum, Michelia figo, and *Schima superba.* Mixed proportion generally was: evergreen/deciduous tree species 3/7; coniferous forest/broad-leaved forest was 3/7; the upper arbors took 70 %. For these forests tree species were more than 100, basically did not plant *populus* sp. and C*innamomum camphora* and oher species have now widely planted in other regions. For planting, the requirement of seedlings was DBH (diameter at breast height) more than 5 cm, the spacing was 3 m by 4 m, while for *Taxodiaceae* trees spacing was 2 m by 2 m, adopting the strip mixed and block mixed.

2. Along the coast of Taihu Lake, in the area from offshore 1 km: The protective forest 30,000 Mu in 2009 had been accomplished, achieved afforestation area of, by strip or block mixed afforestation.
3. Along the coast of Taihu Lake, in the area from offshore 5 km: 5000 shelterbelts construction had been completed in 2010, focusing on four-side tree planting, in which loquat and other fruit trees were planted to promote economic forest development and raise farmer's incomes.
4. Along the coast of Taihu Lake, in the area far away from offshore 5 km: Since 2008–2009, it completed 2.5 ha shelterbelts construction, and the key afforestation sites were on riverbanks from the Lake 10 and 50 km, which linked with the Lake (see Figs. 8.6, 8.7 and 8.8).

Fig. 8.6 Shelterbelts are established along the channel connected with Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 8.7 Protective forests with evergreen trees are established along Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 8.8 Protective forests with deciduous trees are established along Taihu Lake (Photograph taken by Jianfeng Zhang)

8.5 Key Technology of Forests Building

In Taihu Lake watershed, ecological public welfare forests include lakeside shelter forest, levee protective forest, water source conservation forest and farmland shelterbelts, as well four-side trees, which create a good environment around the Lake. Of course, the attention mainly is paid to the construction of water conservation forest, taking into account the landscape requirements, multiple tree species are strip mixed, evergreen and deciduous tree species proportion is about 4/6. In this case, these trees such as *L. lucidum, C. camphora, Cedrus deodara, Salix babylonica, Taxodium* sp. (*Taxodium hybrid, T. distichum, T. ascendens*), *P. stenoptera, K. paniculata, S. japonica, A. altissima, A. julibrissin, and G. biloba,* and other wide adaptability of deciduous tree species are chosen as the main planting tree species, so as to accelerate the speed of forest, establish and increase the vegetation coverage. Implementation of artificial afforestation engineering, the key techniques cover site preparation comprehensively and land levelling, tree species selection and collocation, seedling grading, planting time, planting density, long-term management and protection etc.

8.5.1 Tree Species Selection

For tree species selection, the general principle is choosing the suitable tree species according to the site conditions, e.g., in waterfront sites planting such as *S. babylonica and/or Salix integra*, and in the highland planting such as *S. sebiferum*, *F. simplex, P. chinensis*, *Koelreuteria integrifolia*, *S. japonica*, *A. altissima*, *A. julibrissin*, *G. biloba.* Obviously those trees with adaptability to a wide range are preferred. For example, in the paddy field and in the place with the higher underground water level, *T. ascendens*, *T. distichum,* and willow (or hybrid) should be planted; in the both sides of ponds, *S. babylonica* and *P. stenoptera* planted. At the same time, in the intersection and around the village, oleander, *Nerium indicum*, *L. lucidum*, *O. fragrans,* and other evergreen tree species should be much more planted.

8.5.2 Tree Species Collocation Pattern

The composition and collocation of trees is important for stand structure and functions. In Taihu Lake watershed, afforestation is aiming to protect water security and improve environment. Hence determining a rational forest structure is significant. For riverbank protective forests which connected with the Lake, trees are planted from offshore to extended line respectively *S. babylonica*, *N. indicum*, *S. sebiferum* or *F. simplex* or *P. chinensis*, *K. integrifolia* or *S. japonica* or *A. altissima*, *G. biloba*, *C. camphora* or *C. deodara*, *L. Lucidum,* or *T. ascendens*.

The specific number of rows can be adjusted according to the terrain, and along the channel banks trees are symmetrically planted.

For the protective forest along the Lake west levee within 200 m width, trees are *N. indicum*, *S. sebiferum*, *L. Lucidum*, *P. chinensis* or *Bischofia polycarpa*, *C. camphora*, *K. integrifolia* or *S. japonica* or *A. altissima*, *G. biloba*, *C. camphora* or *C. deodara*, *C. camphora*, *L. Lucidum* and *N. indicum*. The specific number of rows can be adjusted according to the in situ terrain.

8.5.3 Seedling Size and Treatment

For this forest, big seedlings are preferred. Usually container seedlings are applied; seedling diameter for arbors is more than 5 cm; for oleander the best is with more than 4 branches. The height of seedlings is kept 2.2 m for most tree species except ginkgo and cedar; the other top is cut off (see Figs. 8.9 and 8.10).

Fig. 8.9 Seedling size and treatment (Photograph taken by Jianfeng Zhang)

Fig. 8.10 Seedlings are planted (Photograph taken by Jianfeng Zhang)

8.5.4 Planting Density

As a rule, planting density depends upon the afforestation objectives, seedling sizes, and so on. For riverbank protective forests which connected with the Lake, each side not more than 5 rows for the same tree species, spacing between stocks: 2 m × 2 m, strip mixed; for the Lake levee protective forests, 10 rows or less for the same tree is optimal, the total number of rows controlled in 20 or less; spacing between stocks: 2 m × 2 m, strip mixed, too. In the forest edge, plant 1 to the 2 row of *N. indicum*, which is mainly for biological isolation and control of forest edge projection.

8.5.5 Planting Techniques

For afforestation time, in this region deciduous tree planting usually is done before the end of March, and evergreen tree species planted before the end of April.

Certainly soil preparation is the most basic afforestation work, as soil quality is directly related to the effect of afforestation and forest management cost. In terms of regional terrain features, on the basis of perfecting ditch and road construction, it is vital to comprehensively deep plow lands and level, clean up the weeds, and ensure the roads and ditches matching, sites leveling.

1. Road construction: When performing riverbank protective forests building which connected with the Lake, should pay attention to road construction, especially to consider building operation sidewalk in the forest; the road can be built with 3 m wide, a row of trees is planted in each road shoulder from outer margin of 0.5 m. And for the Lake levee protective forests, forest roads with 3 m wide can be built in the forest from offshore 50, 100, and 150 m, north–south direction (see Fig. 8.11).
2. Ditch system construction: At the beginning of site preparation, outside the forests the unified isolation trench not less than 1.5 m (depth) × 2 m (width) must get ready so as to drain water from the forest when flooding happens. For riverbank protective forests which connected with the Lake, along the centerline one forest road has been constructed; meanwhile in one side of the road a drainage ditch is to dig with the requirements of 0.8 m (depth) × 1 m (width), which is called first-grade drainage ditch; then along the forest belt direction every 10 m to dig a north–south drainage ditch, requirements of 0.4 m (depth) × 0.6 m (width), which is called second-grade drainage ditch; lastly between 10 m forest belt every 4 m to dig the west–east drainage ditch, 0.2 m (depth) × 0.3 m (width) above, which is called third-grade drainage ditch. Hence, the drainage ditch system is formed. For the Lake levee protective

Fig. 8.11 Forest road is built (Photograph taken by Jianfeng Zhang)

Fig. 8.12 Planting hole is made (Photograph taken by Jianfeng Zhang)

Fig. 8.13 Planting trees in Yixing (Photograph taken by Jianfeng Zhang)

forests, the similar drainage ditch system also is needed and should be completed.

3. Planting hole digging: According to the principle of deep digging and shallow planting, for riparian upland sites, the hole shall not be less than 60 cm × 60 cm × 60 cm; for cultivated land sites, planting hole shall not be less than 50 cm × 50 cm × 50 cm (see Fig. 8.12).
4. Planting method: In order to ensure planting at the optimal season, the time from lifting to seedling planting completing shall be kept within 24 h. After planted immediately pour water through the root, uniformly cover film, then all the film with 5 cm thick soil covering the whole (see Fig. 8.13).
5. Maintenance method: It is necessary for pest control, forest fire prevention, and flood disaster, in the absence of big drought without watering.

8.6 Discussion and Conclusions

In terms of the current environmental problems and ecological requirements in Taihu Lake watershed, the function and development strategy of ecological public welfare forest is discussed in this chapter. According to the social and economic development state and urbanization trend, the construction of ecological public welfare forest in Taihu Lake basin is significant to cope with the problems existing and to push up ecological construction, as well to increase farmer's incomes. Hence, the method of modifying structure, enhancing management, and strengthening functions in future is put forward, which stresses that should pay attention to cultivate mixed forests with multi storied, and to enhance integrating of ecological function and ornamental. Finally, the emphasis is on strengthening the management of ecological forest. All commercial logging should be banned; the snags, windthrow, rot wood, and natural withering on the brink of dead trees are under management, so as to improve forest health, prevent pest's outbreaks, and promote forest growth. The selective cutting can be carried out for maintaining forest health, but artificial planting after cutting is necessary. The forest management technology of Ecological Public Welfare should be implemented based on ecological construction instead of commercial benefits, in accordance with the natural succession law of forest community, preparing forest management plan, implementing maintenance and tending with near-nature forestry measures, in order to existing forest gradually restored to the zonal climax forest communities (Xuan et al. 1999; Zhang et al. 2008).

In addition, we shall take full advantage of the kinds of resources; enhance economic development, such as carrying out forest tourism, developing a variety of operations, and deep processing, etc., so that the recycling part of the funds is used for the construction of ecological forest. In order to play the forest ecological and social benefits, make full use of the advantages of environment and resource conditions, make the resource advantage transform to economic advantage, increase its own development ability and economic strength, form a healthy development pattern.

References

Chai SW, Pei XM, Zhang YL et al (2006) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conser 20(6):191–194

Chen JL, Pan GX, Zhang AG et al (2002a) Controlling effects of shelter forest on non-point source pollution of agricultural lands in Taihu Lake area. J Nanjing Univ (Nat Sci Ed) 26(6):17–20

Chen JL, Shi LL, Zhang AG (2002b) Controlling effects of forest belts on non-point source pollution of agricultural lands in Taihu Lake area China. J Res 13(3):213–216

Ding X, Shen Z, Hong Q et al (2010) Development and test of the export coefficient model in the upper reach of the Yangtze River. J Hydrol 383(3/4):233–244

Gu FC, Li YW, Jiang QA et al (1995) The frame of forest management in China. Res Manag 5:2–27

Jiao JQ, Guo JH, Ma JM et al (2000) The ecological public-welfare forest construction for the protecting project area of the natural forest resources in the middle and upper reaches of the yellow river in inner Mongolia region. Inner Mong Invest Des 1:5–8

Su YW, Huang JL, Wang YG (1999) Preminary discusson of technical standard of eco-public forest in hunan province. Cont South Invent Plan 18(3):48–51

Xuan ZC, Yuan XH, Wu GH et al (1999) Discussion on several important questions about ecological forest. J Zhejiang Sci Tech 19(3):53–57

Xue L, Chen HY (2000) Development tendency of the world forests. Sci Tech 16(2):38–42

Xue D, Luo S, Xue L (2001a) Functions of eco-landscape forest in cities. Urban Plan Forum 6:77–78

Xue D, Xue L, Luo S (2001b) The effect of gardens and urban forests on urban eco-environment. Urban Stud 8(1):54–57

Yang GS, Wang DJ et al (2003) Economic development, water environment, water disaster. Sci Press, Beijing

Yong STY, Chen W (2002) Modeling the relationship between land use and surface water quality. J Environ Manag 66(4):377–393

Yu LZ (1999) The construction of ecological public welfare forest in mountainous areas of Liaodong. J LiaoNing Sci Tech 5:32–35

Yu XX, Yang GS, Tao Liang (2002) Effects of land use in Xiaotiaoxi catchment on nitrogen losses from runoff. Agro-Environ Prot 21(5):424–427

Zhang JF, Qin GH (2007) Poplar-based agro-forestry in China and its economic analysis. Shandong science and technology press, Jinan

Zhang JF, Sun QX (2005) Review on agroforestry systems in China. Chin Sci Tech 4(3):80–84

Zhang JF, Fang MY, Li S (2007) Developing agroforestry in slopelands to combat non-point pollution in China. Chin Sci Tech 6(4):67–72

Zhang JF, Shan QH, Qian HT et al (2008) Effects and planting techniques of hedgerow intercropping on sloping lands in agricultural non-point source pollution control. Bull Soil Water Conserv 8(5):180–185

Zhong QL, Xie LY, Qiu SW (1999) A study on the types and the benefit evaluation indicator systems of ecological forests. Acta Agr Univ Jiangxiensis 21(1):103–106

Chapter 9
Effects and Planting Techniques of Hedgerows in Slope Lands for NPS Pollution Control

Abstract With population growing, the demand on gains and fruits is increasing. Thus, slope fields are paid a great attention in order to gain much more products. For controlling non-point source (NPS) pollution from the sources, managing slope lands rationally in the headwater regions is necessary. It has been approved that contour hedgerow system is the most favorable art for water and soil conservation, which is considered as a vital measure to control agricultural NPS pollution in practice. By implementing hedgerow intercropping, it can fix nitrogen through plants to reduce chemical fertilizer input, prevent soil and water erosion, uptake soil nutrients and hold up pollutants; thus N and P were reduced by 89 and 80 % respectively through hedgerows, which is helpful to provide habitat for wildlife. Moreover, the planting techniques of hedgerows in slop fields also were discussed in the paper such as design of the system, methods of site preparation, type of planting, and tending and maintaining measures. The key techniques are as follows: Taking suited method for site preparation, generally the depth is 30–40 cm; establishing hedgerow usually by seedling planting, one row, two rows, or more, the row distance is 3–7 m; for herbs or scrubs, the spacing is 5–10 cm × 20–60 cm; planting is fulfilled in the spring or before the tree budding.

Keywords Hedgerow · Intercropping · Non-point source pollution · Slope land · Effect · Planting technique · Water and soil conservation

Although China's territorial area is about 9.6 million km^2, the tillable field resource is very little which is only about one billion ha. With population increasing and urbanization process speeding up, tillable field area in which soil quality is fine and especially has higher productivity is decreasing year by year. During 1978–1997, net reduction of tillable field per year reached up to 25×10^4 ha, and at the same time, domestic population net increased by 14.5 million per year. The dual pressures from both cultivated land reduction and population increasing intensify the conflict between human and fields that already is in serious state. In order to satisfy increasing demand on grains and other agricultural products in some places, deforest and irrational reclamation on farmlands are getting much more violent even some steep slope lands become cultivated land. At present, the area of cultivated slope land is about 4×10^7 ha. In these lands it is much more easily resulting in water and soil erosion.

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9.1 Introduction

At present, there are water and soil erosion area of 3.67 million square kilometer, taking 38.2 % of national territorial area, of which water erosion area is of 49 %. There is five billion tons eroded soil yearly in the country, for 1 ton soil loss, which generally contains 2.55 kg nitrogen, 1.53 kg phosphorus, and 5.42 kg potassium (Quan and Yan 2002). There are two main reasons leading to water and soil erosion, and the first is farming in slope fields and steep slope tillage largely increasing and no effective water and soil conservation measures; the other is naturally grown plants that have been destroyed and vegetation coverage decreased which consequently aggravates water and soil erosion (see Figs. 9.1 and 9.2).

Fig. 9.1 Soil and water erosion in Anji (photograph taken by Jianfeng Zhang)

Fig. 9.2 Water is polluted by soil and water erosion in Anji (photograph taken by Jianfeng Zhang)

Obviously, water and soil erosion causes ecological environment worsening, field productivity decreasing, tillable land area reducing, rivers and lakes silting up, and hazards of drought and flood occurring frequently, which straightly threaten the safety of urban and villages. Furthermore, another result of water and soil erosion is badly leading to water eutrophication and contamination.

The total area of domestic lakes is about 83,400 km^2, accounting for 0.8 % of national land area. Due to kinds of pollutants, a large part of freshwater lakes and rivers are both suffering from moderate pollution, and more than 75 % of lakes suffered from eutrophication (Zhang et al. 2004). Researches show that algal booms will happen in lakes and reservoirs when inorganic nitrogen content is more than 0.2 mg/l and phosphate content is more than 0.01 mg/l. According to the survey, in Taihu Lake area, the loss of pesticides and chemical fertilizers from fields takes more than 50 % of contribution rate, and ammonia–nitrogen loss from urban surface water takes 30 % of contribution rate when Taihu Lake pollution accident happened in 2007 in Wuxi. In Dianchi Lake, agriculture NPS pollution takes 43.3 % of contribution rate to total nitrogen and takes 37.1 % of contribution rate to total phosphorus. This is because excessive chemical fertilizers were applied, and there were at least 6 thousand tons nitrogen and 2.8 thousand tons phosphorus flowed into Chaohu Lake per year. At present, the N/P ratio of Chaohu Lake water is approaching the critical point of algae boom occurring. There is about half of lakes in the country being in the state of serious eutrophication, and agriculture NPS pollution is one of the main causes (The National Bureau of Statistics China Environment Statistical Task Forces 2000; Zhang et al. 2004; Zhao et al. 2007).

Therefore, it is extremely important and significant that building plant fence with nitrogen-fixing species and taking others effective measure for governing slope fields, in order to prevent water and soil from erosion and reduce agriculture NPS pollution.

9.2 Theory of Agriculture NPS Pollution Control from the Source

As discussed above, there are many factors leading to agriculture NPS pollution, generally speaking pollutants coming from agriculture chemical substances input into soils. Hence, it indicates that the process of NPS pollution from formation, migration, and transformation actually is pollutant diffusion from pedosphere to other sphere, especially hydrosphere. Compared with industrial pollution and domestic pollution, agriculture NPS pollution is widely distributed, and its occurring time and sites are in uncertainty. Therefore, its management and control are much more difficult, and the mission we faced is more arduous (Li 1999; The National Bureau of Statistics China Environment Statistical Task Forces 2000; Zhang et al. 2004).

As to the occurrence and consequence of agricultural NPS pollution, usually there are three approaches to implement control from source (occurring) and process (draining) to end (contaminating water) (Schultz 1995; US Environmental Protection Agency 2003; Young 1989). No doubt, source control is the most important way among the three stages.

Source control aims at preventing and reducing pollution from the source by decreasing chemical fertilizers and pesticides applied, improving soil characters, and averting water and soil erosion. As a general, the way is to improve soil physical and chemical properties by increasing forest coverage, enhancing soil fertility, and consequently decreasing water and soil erosion (Magette 2000; Zhang and Qin 2007).

According to the theory of soil biothermodynamics, soil fertility is not only meaning soil nutrients content, but also meaning the capacity of nutrients supplying. For most of the soils, they can provide about 40 % of nutrients that crops need, sometimes it may reach 60 % (Mander et al. 2000), and certainly the rest must be from fertilizers applied. Apparently for normal agricultural production, fertilizing is necessary and helpful, especially when expect to raise farmland productivity. Actually, for fertilizers application, the key is to keep three "balances": organic and inorganic fertilizers; fertilizers of nitrogen (N), phosphorous (P), and potassium (K); and fertilizers of major elements and micro elements. In terms of the current conditions of fertilizers application, the first thing is to increase organic fertilizers and enhance soil fertility; the second thing is to control and diminish nitrogen fertilizers application. In general, when practicing fertilizers application, keeping the ratio of N, P, and K (1:0.3:0.5) is optimum (Daniel et al. 1998). Meanwhile, it is also vital to increase the use of silicon fertilizer, boron fertilizer, zinc fertilizer, etc. Additionally, in order to strengthen the biological nitrogen fixation, conducting intercropping of legume and non-legume crops is to advocated, and it is beneficial for decreasing dosage of chemical nitrogen fertilizer (Lena 1994).

There are different parameters to indicate soil fertility, such as contents of N, P, and K, and soil organic matter content. This index illustrates the soil fertility level from a different angle. However, soil fertility is a dynamic change process, and static index can not roundly evaluate soil fertility situation. In view of this, people come up with a concept named soil system entropy (Mander et al., 2000; The Fertilizer Institute 1990). Soil system entropy is expressed as follows:

$$S = \int \frac{\mathrm{d}H}{G}$$

where G means effective substances per unit formed by energy substances decomposing or artificially inputting substances and dH substances' potential energy loss.

For soils, organic matter and soil humus are energy substances. If there are fertilizers applied artificially, the economic output of crops is at the cost of consuming soil humus. Because the ratio of C/N (carbon/nitrogen) of humus approaches to be constant, a certain amount of nitrogen correspondingly decomposes a certain amount of humus. Soil system entropy can be calculated through the equation.

$$\Delta S = \frac{\text{humus quantity per mu} \cdot D_{\mathrm{N}} \cdot \varphi_{\mathrm{N}} - \text{output per mu} \cdot D \cdot K_1}{\text{total nitrogen per mu} \cdot D_{\mathrm{N}}}$$

where D_{N} is the mineralization rate of humus and organic nitrogen; φ_{N}, $K_{1,}$ respectively, means energy coefficient transformed from humus and crop seeds.

Thus, entropy means that energy substances potential energy losing with soils consuming organic nitrogen per unit soil weight under the case of no fertilizers applied artificially, which is an indicator of the substance energy transforming efficiency.

According to the theory of soil biothermodynamics, the measures of enhancing soil fertility and raising agricultural yields mainly include the following: (1) to build forest shelter belts for croplands and improve land environment; (2) to plant green manures, implement comprehensive management, and promote biological nitrogen fixation; (3) to use organic fertilizers and azotobacter fertilizers; and (4) to perform farming system of no-tillage. In a word, we should combine local socioeconomic development situation with climate, soil, and other natural conditions, strive to develop slope field agroforestry, modify agriculture management, decrease dosages of chemical fertilizers, pesticides, and herbicides, build riparian forest buffers on gully and water banks, reduce water and soil erosion, conserve biodiversity, and finally control agricultural NPS pollution (Xing and Zhang 2006).

9.3 Effect and Benefits of Slope Land Nitrogen Fixation by Hedgerows

During the process of agricultural NPS pollution occurring, the soil has dual character, i.e., on the one hand, it suffers straightly from the harm, leading to its physical and chemical properties getting worse, and fertility level decreased; on the other hand, after the soil was polluted, surface soil that contained high-level contamination easily went into atmosphere and water under the impact of wind and water runoff, resulting in air pollution, surface water pollution, underground water pollution, and ecosystem degeneration and other secondary ecosystem environmental problems.

At present, in the upstream regions of rivers, lakes, and reservoirs, the lands are mostly agriculture-oriented. Local people in order to pursue higher economic benefits from the lands, their farming system is becoming much more exquisite, and the field management is getting much more intensive. Under the circumstances, the amount of chemical fertilizers, pesticides, and herbicides is increased year by year, and soils are of overnutrition (Zhang et al. 2004; Wen et al. 2004). However, slope land is a main landform in this area, water and soil loss easily happening, therewith the nutrients in soil enter water systems and lead to water eutrophication. In this case, it is necessary and significant that build nitrogen fixation contour hedgerows in slope lands.

Nitrogen fixation contour hedgerow is a kind of agroforestry management, or called hedgerow intercropping. Usually, its establishing is firstly selecting woody nitrogen-fixing plants and then planting and banding these plantlets intensively according to the certain spacing along the slope land contour (see Figs. 9.3 and 9.4). Clearly, its benefits are multiple, such as taking use of biological nitrogen fixation measures, reducing the amount of chemical fertilizer application, and maintaining certain of soil productivity. In practice, maintenance measures of hedgerow intercropping are pruning nitrogen-fixing plants at right time and controlling its height at appropriate level and mowing leaves as green manure (Zhang and Sun 2005; Liu and Li 1997; Sun et al. 2004).

From the above discussion, it could be shown that features and functions of hedgerow intercropping are as follows: (1) Taking advantage of nitrogen-fixing plants to fertilize soils. Compared with chemical-oriented nitrogen, the nitrogen fixed by biological approach can be all used easily by plants. It is estimated that 2 tons pure nitrogen from chemical fertilizer just has the same effect with 1 ton nitrogen fixed by biological way; 1 ton biological nitrogen at least amounts to 44 tons urea. The biologically fixing nitrogen all around the world is 14–17 million tons (Tang et al. 1999), which amounts to 61.6–74.8 million tons urea. The much more important is nitrogen fixing by biology and this process will not contaminate environment. (2) Controlling water and soil erosion. Hedgerows have intercept effect and it can improve soil physical property; thereby, it can conserve water and soil efficiently, decrease nutrient loss, and enhance soil biological activity. (3) Producing certain of economical benefits. Hedgerows consist of evergreen perennial nitrogen-fixing plants, and some of these plants contain abundant crude

Fig. 9.3 Nitrogen fixation hedgerow of *Amorpha fruticosa* Linn. in Anji (photograph taken by Jianfeng Zhang)

protein, for instance, the crude protein content in *Leucaena leucacephala* branches and leaves approaching 18–24 %, which are excellent stock feeds. Hence, developing the processing industry can improve farmer's financial incomes and promote industrial structure adjustment in this area. In addition, hedgerow can provide fuelwoods, for example, *L. leucacephala* contour hedgerow that interplanted by 4 m on slope farmland can provide 14–30.5 ton ha^{-1} branches and leaves per year, which is helpful to alleviate energy shortage problem for local people.

In terms of controlling agriculture NPS pollution, building hedgerows upstream and littoral zone of rivers, lakes, and reservoirs is crucial and significant. At first, it can reduce surface runoff and intercept most of cropland nutrient loss; secondly, it can take advantage of the complementarities of soil nutrient absorbing by different plants, ensure excess nitrogen, phosphorus in soil to be absorbed as more as possible. Hence it is helpful to reinforce nitrogen, phosphorus cycle in soil ecosystem, prevent water pollution fundamentally (Yi 1995; Xu et al. 2002) (see Figs. 9.5 and 9.6).

As early as in 1950s, USDASCS (United States Department of Agriculture Soil Conservation Service) came up with hedgerow application. In 1991, the research on water and soil erosion control by hedgerows was done in USA. The results were shown that hedgerows could reduce 60 % of surface runoff and 75 % of silts (Zhong 2004). Since 1994, hedgerows had been widely applied in America as an efficient water protection measure.

Fig. 9.4 Nitrogen fixation hedgerow of *Lycium barbarum* Linn. in Anji (photograph taken by Jianfeng Zhang)

There are other researches showing that nitrogen interception ratio by riparian vegetation buffers can reach 89 %, while interception ratio by crops is only just 8 %; for phosphorus, the interception ratio is 80 and 41 %, respectively (Daniel et al., 1998; Zhong 2004). Thus, it can be seen that hedgerow is better than crop intercept in the viewpoint of control nitrogen and phosphorus loss. The research did by Sun Hui et al. in Sichuan Province reflected that among different nitrogen-fixing plants, available phosphorus content in soil layer which is below hedgerow 20 cm was less than that in soil layer below middle part of riparian vegetation 20 cm, which indicated that hedgerows had obvious effect on absorbing available phosphorus in soils (Sun et al. 1999, 2002, 2004).

After planting hedgerows on slope cropland, the length of surface runoff moving on the slope will be shorten, which can reduce the loss rate of surface runoff, as slope cropland surface runoff is intercepted by hedgerows. On the one hand, it prolongs infiltration time of surface runoff; on the other hand, it can greatly decrease the loss rate of surface runoff. And when soil water infiltration state is improved year by year, water and soil erosion of slope croplands will be controlled efficiently. Another research done by Liao xiaoyong et al. also confirmed the effect. It shows that after three years of hedgerows plantation, the surface runoff reduction rate could approach 50–70 %, and the soil erosion reduction rate could reach up to 97–99 % (Chen et al., 2003; Liao et al. 2006); in this case, water and soil erosion

Fig. 9.5 Hedgerows grow in riparian slops (photograph taken by Jianfeng Zhang)

Fig. 9.6 Hedgerows grow in hillslopes (photograph taken by Jianfeng Zhang)

would be controlled completely. After several years of regular management, tillage strips between hedgerows can form terrace lands, and compared with terrace land which was constructed by artificial engineering, these natural terrace lands have obvious advantages. It not only changes from slope lands to terrace lands, but also keeps soil fertility under the situation of reducing chemical fertilizers application. Meanwhile, it produces fodders and fruits, yields a certain of financial benefits, and basically achieves the goal of slope cropland management.

Thus, in order to control agriculture NPS pollution, the attention should be paid to improve soil property and prevent water and soil erosion. No doubt, developing slope land agroforestry systems and constructing hedgerows is a very efficient way (Young 1989; Peterjohn and Carrell 1984).

9.4 Planting Techniques of Hedgerows in Slope Lands

Hedgerow is characterized by continuous or nearly continuous type of narrow belts, consisting of woody plants or some herbage with strong stem. The density of hedgerows is high, and usually, these plants can cover field surface or nearby. As a rule, planting woody plants or perennial herbage is advocated, which can produce some economical benefits, also can control water and soil erosion and consequently enhance soil property, and increase land productivity, too. Normally, there are two main forms for hedgerows building: One is cash tree hedgerow + crops; the other is cash tree hedgerow + economical crops (Shen 2002).

9.4.1 Design Principle

In practice, hedgerows construction emphasizes on NPS pollution preventing and reducing. So when we design the structure, selecting a reasonable location for hedgerows growing is the determinate condition for them to perform the effect on intercepting runoff. Generally, the actual operation method is according to local landforms, and hedgerows are built in downhill of slope lands along the contour, going vertical with runoff flow direction (see Fig. 9.7). When the slope length is long enough, usually several contour hedgerows could be established at the same slope land to alleviate runoff step by step (Xu et al. 1999). If the site of hedgerows is chosen unreasonably, most of runoff would bypass hedgerows and straightly drain into receiving waters. Therefore, in this case, the effect that intercepts NPS pollution will decline significantly. Additionally, sometime hedgerows are planted along rivers and reservoir banks, protecting riverbanks with plants or plants combined with civil engineering and forming a transitional buffer zone for the ecosystem that water and land intersect together. Under this case, it emphasizes on

Fig. 9.7 Hedgerows are built along the contour, going vertical with runoff flow direction (photograph taken by Jianfeng Zhang)

the function of water quality protection, and multiple goals are to be strengthened such as water and soil erosion control, sands and mud filtration, silts and chemical pollutants absorption, water temperature adjusting, aquatic organism biodiversity conservation and riparian banks stabilization.

Planting hedgerows against water and soil erosion should take several conditions into consideration such as slope gradient, slope form, and soil physical property. Usually, every other 3–7 m on slope lands along the contour, single row, double row, or multirow woody plants and herbage are planted intensively. Selected plants are required to grow fast, resist degraded soil conditions, regenerate by stumping easily, and bud earlier. Meanwhile, it is better for these plants that their root system is developed, and soil fixing capacity is powerful. The spacing for herbages or under shrubs is 5–10 cm among plantlets and 20–60 cm among rows. While for the other woody plants the spacing is determined by actual situation, it depends upon (Tang et al. 2001). Obviously, those woody plants and herbaceous plants which have good ecological benefits and economical benefits should be planted between two hedgerows. In order to avoid damage to soils, when constructing hedgerows, we should pay attention to apply seeds of the trees or grasses that can fix nitrogen and fertilize soil for stand establishing.

9.4.2 *Soil Preparation*

9.4.2.1 Methods of Soil Preparation

Soil preparation for strip ditching: This is suited to apply for hedgerows at mountains, hilly regions, and northern grasslands. Soil preparation of ditching at mountains and hilly areas should be done along the contour. The ditching width of hedgerow strip mostly is above 30 cm, and it can be adjusted in line with actual landform conditions. The length of the strip is determined by landform, the best being not too long and keeping native vegetation retention from part to part (Zhang and Qin 2007; Xing and Zhang 2006).

Soil preparation for hole digging: For tree planting, digging holes is a widely accepted soil preparation method at mountains and hilly and plain areas. Particularly for mountains and steep slope lands, they easily suffer from water erosion and wind erosion, so in these places, this method should be even more applied (see Fig. 9.8). The general standard of soil preparation for hole digging is that the diameter of holes is kept 10–60 cm; when hedgerows consist of shrubs and herbages, the size will be smaller to a certain degree. At mountains and hilly areas, in order to decrease soil disturbance and reduce soil and water erosion, usually soil preparing entirely is not advocated and high specification soil preparation, too.

Fig. 9.8 Planting holes are made (photograph taken by Jianfeng Zhang)

9.4.2.2 Depth of Soil Preparation

The depth of soil preparation in afforestation for coniferous trees should approach 30 cm; it may reach 40 cm in northern arid and semiarid regions, while for broad-leaf trees, the depth should be more than 40 cm (Zhang et al. 2007; Peterjohn and Carrell 1984). Actually when planting trees, the depth of soil preparation is decided by species of selected trees, shrubs, and herbages; also it is defined by afforestation sites and seedling sizes, too.

9.4.2.3 Time of Soil Preparation

Soil preparation is usually done a month before afforestation. In the areas suffered with frost heaving injury, soil preparation in advance is not necessary in spring. For planting trees by digging holes, the best soil preparation time is when the afforestation action is practiced. In arid and semiarid areas, soil preparation should be done in rainy season and afforestation is then performed.

9.4.3 Planting Technology

9.4.3.1 Methods of Seedling Planting

Planting by digging holes: As a rule, the size and depth of holes should be bigger than seedling roots (see Fig. 9.9). Seedlings must keep vertical with ground, letting roots stretch freely; the depth of holes must be suitable. After filling half of soil in the hole, tread down, then fill soil, and tread fully. At last, slightly cover the hole with some surface soils. For conifer seedlings, strip ditches or slotting planting is advocated. When performing afforestation, just do slotting on sites that soils have already been prepared with hoes or shovels, then put seedlings in, decide suitable depth, and ensure seedling roots stretching; afterward pull out the tool and fill soils.

Depth of planting holes: Usually, the depth of holes is decided according to site conditions, soil features, and tree species; it is optimal that the depth is a little bigger than seedling roots. The trees are planted at arid areas and sand soils, and the depth should be deeper to some extent as trees can grow deeply into the soils for absorbing sufficient water.

Seedling treatment: There are several methods of seedling treatment according to tree species, seedling features, and soil conditions, such as taking plantlet top off, cutting stem, trimming roots, cutting leaves, picking buds, soaking roots, or mudding roots (see Figs. 9.10 and 9.11). Moreover, seedlings also can be treated with rooting-activating agent, rooting powder, transpiration retardant, and mycorrhizal inoculum. Before planting, seedlings should be graded in accordance with the standard. Mostly, container seedlings are advocated, but the container must be removed before planting under the case of roots not easily penetrating.

Fig. 9.9 Size of planting holes is controlled (photograph taken by Jianfeng Zhang)

Fig. 9.10 Seedlings are packaged when transported (photograph taken by Jianfeng Zhang)

Fig. 9.11 Seedlings are mudded before planting (photograph taken by Jianfeng Zhang)

Planting by cuttings: Recently, afforestation with cutting is getting popular in some place, especially for those tree species rooting easily. For most tree species, we can choose annual or biennial branches as cuttings, the length of one cutting is 30–50 cm, and the diameter is 1.5–2.0 cm. The cutting usually is deeply buried and leave a few exposing above the ground (Liu et al. 1997; Sun et al., 2005).

9.4.3.2 Methods of Sowing

At present, direct seeding is one of the important methods of forestation. Usually, this planting way can be used when the resource of seeds is abundant; the tree is easy to sprout and has drought-resistant character. In this case, soil preparation in advance is necessary for artificial seeding afforestation. Sowing seeds in holes or strip ditches is usually operated when soil conditions are well. For difficult sites, broadcast sowing in rainy season is suited to manipulate.

Quantity of seeding: It is determined by quality of seeds, site conditions, and planting density.

Covering soil thickness of artificial seeding: For sowing seeds in holes or strip ditches, the covering soil thickness usually is three to five times of seed diameter. Also the covering soil thickness is related to soil textures: For sandy soil, it can be a little deeper (US Environmental Protection Agency 2003), while for clay soil, it can be a little thin. In order to decrease soil evaporation and maintain moisture, after sowing covering with burned soils or other mulching also is helpful and beneficial.

9.4.3.3 Planting Season

Afforestation in spring: In China, nearly all over the country, planting trees could be implemented in spring. Normally, detail planting time is according to different phenological period of tree species and soil thawing conditions, i.e., carry out the action after soil thawing in case of soil frozening and naturally before tree sprouting. Afforestation in rainy season: Tree planting in this season is suited for those species whose seeds are small or seedlings are from container nursery. In this case, we should pay attention to rain conditions, especially intensity and lasting time of rainfall; implement afforestation at right time.

Afforestation in autumn: In some regions where there is not frost heaving injury, afforestation can be done at late autumn or early winter. In this season, for some broad-leaved tree species stock planting is suited. It is noticed that if planting by seeding in the season, these seeds should have big size, hard shell, long period of dormancy, and do not need storage. If the weather is in drought, soil moisture content is too low, and without irrigation condition, afforestation should be delayed to some time. As discussed above, planting time is various depending upon the tree species and soil conditions. But when afforestation by container seedlings, it is not limited by seasons.

9.4.4 Maintenance and Management

Soil management and weeds control: After hedgerows are constructed, the emphasis should be paid on soil management and weeds control according to actual demand of the stand, combining with seedlings supporting and vines removing. For those weeds and others useless, they should be removed as early as possible. If weeds are not removed completely and grow densely, man should cut off them in time, as they will compete soil nutrients and water with seedlings. Normally, this tending must last for three years and be done one to three times per year. In the area where frost damage happens, removing weeds is the major assignment and the times of soil loosening can be reduced in the first year the stand is established (Zhong and Tang 2001). Anyway, the basic requirement of soil management and weeds control is not hurting seedling roots.

Replanting and resowing: Sometime if the survival rate of seedlings is unqualified, it is necessary to replant or resow in time. When do replanting, big stocks with the same age should be chosen.

Plantlets management in field: In order to raise vegetation coverage, when hedgerows are established, usually the density of seedlings is higher. Thus, with plantlets growing, thinning is necessary. It may be done one or two times, so that make seedling number per unit area to approach the requirement of hedgerow density.

Stems cutting and regrowing: For some stands, plantlets may suffer from drought, frost, mechanical damage and pest and disease damage, and consequently grow badly. If these trees sprout easily, the operation that cut the stem off and make it regrow can be done.

Prevention and control of diseases and pests: For disease and pest control, the principle should be carried out that prevention is the first, and prevention and control is performed comprehensively. In order to fulfill and complete the assignment, forecasting of diseases and pests should be done in a timely and accurate manner. And the prevention measures include biological, chemical, and physical approaches. Additionally, it is necessary to cut off the fruits, branches, and leaves suffering from diseases and pests; to remove the plant damaged badly by disease and insect pest; and to burn it. It is important to control strictly the spread of diseases and pests as well and to strengthen quarantine and prohibit transporting seedlings from the infectious area.

For prevention and control of diseases and pests, we should choose pesticides with high efficiency and low residues. Meanwhile, the attention should be paid on the suitable dosage and application method. For cash crops, the pesticide residues on fruits shall not exceed the standards prescribed by the state. Under the context, biological pesticides are advocated. Biological control measures and utilization of natural enemies also are encouraged.

For newly established hedgerows, it is vital to properly protect and prevent man-made destruction, to mow the weeds timely. Usually, the conifers easily suffer from cold and drought damage, and in winter, the measures of covering soils or grasses should be taken for those trees (Xu et al. 2002; Yuan et al. 2000).

9.5 Discussion and Conclusions

As we mentioned above that nutrient load in some waters is rather large, the status of water quality declining is still serious, and apparently controlling agricultural non-point source pollution is necessary and crucial. The method is based on the principle of soil biological thermodynamics, considering soils as the main research object, relying on biological measures to improve soil fertility. Its purpose is to reduce the input of agricultural chemicals and to improve the agricultural production environment by developing ecological agriculture and agroforestry system, so as to fundamentally to achieve the objective controlling agricultural non-point source pollution. In view of the major character that agricultural non-point source pollution is mainly caused by surface runoff and diffusion, no doubt soil and water loss prevention and reduction is the key solution to water body pollution (Shi 1999). In regard to soil and water conservation measures, we can from the two aspects discuss: on the one hand is to make the surface soil stabilization or increase vegetation coverage to reduce raindrop impacting on surface soil; On the other hand is to make slope level decline, by canalization means to disperse runoff or lower velocity, decreasing runoff erosion, and reducing the amount of rain overflow in the ground. Around these two aspects, a lot of water and soil conservation technology plays an important role in the prevention and control of water pollution. Obviously, hedgerow building is one of the vital approaches. As hedgerow is able to shorten the length of the surface runoff in slopes, it can reduce the flow velocity of runoff and enhance the interception of surface runoff through the layers of alley cropping. In this case, on the one hand, it extends the time of the infiltration of surface runoff; on the other hand, also it greatly reduces the speed of surface runoff. Thus, water infiltration state could be improved year by year, and soil and water loss could be effectively controlled. For the construction of forest ecosystem, the priority is given to nitrogen-fixing hedgerows, ecological ditch, and ecological interception system, especially paying attention to cultivate forest resources in the upstream of rivers, lakes, and reservoirs. Besides ecological benefits, there are other socioeconomic interests through forests establishing, i.e., improving the utilization of land resources and increasing the incomes of local farmers.

Hence it can be concluded that afforestation is significant and its functions are multiple, such as combating agricultural runoff, reducing water and soil erosion, absorbing and utilizing rural domestic sewage of substances including nitrogen and phosphorus, strengthening nitrogen and phosphorus cycle in terrestrial ecosystem. No doubt, this is meaningful to alleviate the situation of water eutrophication, to reduce the pollution of water bodies and to improve the environment.

References

Chen ZJ, Liao XY, Liu SQ et al (2003) Applying hedgerows to improveslope cropland productivity. J Soil Water Conserv 17(4):125–127

China Environmental Statistics (2000) The National Bureau of Statistics China Environment Statistical task forces. China Environmental Science Press, Beijing, pp 35–60

Daniel TC, Sharpley AN, Lemunyou JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Envir Qual 27(1):251–257

Lena BV (1994) Nutrient preserving in riverine transitional strip. J Hum Envir 3(6):342–347

Li XB (1999) Charge of arable land area in China during the past 20 years and its policy implications. J Nat Res 14(4):329–333

Liao XY, Luo CD, Chen ZJ (2006) Effect of hedgerows on soil fertility of slope croplands in three gorges reservoir area. Bull Soil Water Conser 26(6):1–3

Liu XJ, Li XB (1997) Progress of the research on living contour hedgerows in improving sustainability of sloping land utilization. Prog Geog 16(3):68–78

Magette WL (2000) Monitoring. In: Ritter WF, Shirmohammadi A (eds) Agricultural non-point source pollution. LEWIS Publishers, London, pp 205–228

Mander U, Ain K, Valdo K et al (2000) Nutrient runoff dynamics in a rural catchment: influence of landuse changes, climatic fluctuations and ecotechnological measures. Ecol Eng 14:405–417

Peterjohn WT, Carrell DL (1984) Nutrient dynamics on and agricultural watershed: observation on the role of a riparian forest. J Ecol 65:1460–1475

Quan WM, Yan LJ (2002) Effects of agricultural non-point source pollution on eutrophication of water body and its control measure. Acta Ecol Sin 22(3):291–299

Schultz RC (1995) Agroforestry opportunities for the United States of America. Agrofor Syst 31:117–132

Shen YC (2002) Improvement of land productivity by applying hedgerows in three gorges reservoir area. Res Envir Yangtza Bas 11(1):56–59

Shi DM (1999) Analysis on the relationship between soil and water loss and flood disaster in Yangtze River Basin. J Soil Water Conserv 5(1):1–7

Sun H, Tang Y, Cheng KM et al (1999) Effect of contour hedgerow system of nitrogen fixing trees on soil fertility improvement in degraded agricultural slope lands. Chin J Appl Envir Biol 5 (5):473–477

Sun H, Tang Y, He YH et al (2002) Studies on soil nutrient redistribution under contour hedgerow system. Chin J Eco-Agr 10(2):79–82

Sun H, Tang Y, Xie JS (2004) Research and application of hedgerow intercropping in China. J Soil Water Conserv 18(2):114–117

Sun H, Xie JS, Tang Y (2005) Root system distribution patterns of contour hedgerows on slope lands in dry valley of Jinsha river. Sci Sil Sin 41(2):8–15

Tang Y, Chen KM, Xie JS et al (1999) Potential of nitrogen fixing plants for sustainable mountain agricultural development. Geog Res 13:73–78

Tang Y, Xie JS, Chen KM et al (2001) Contour hedgerow intercropping technology and its application in the sustainable management of agricultural sloping lands in the mountains. Res Soil Water Conserv 8(1):104–109

The Fertilizer Institute (1990) Fertilizer facts and figures. Washington

US Environmental Protection Agency (2003) Non-point source pollution from sgriculture. http://www.Epa.gov/region8/water/nps/npsurb.html

Wen J, Luo DQ, Luo XB et al (2004) Agricultural non-point source pollution and control measures of Qiandao Lake area. J Soil Water Conserv 18(3):126–129

Xing SJ, Zhang JF (2006) The Yellow River Delta land degradation mechanism and vegetation restoration technology. China Forestry Publishing House, Beijing, pp 5–15

Xu F, Cai QG, Wu S et al (1999) Effect of contour hedgerows on soil nutrient loss in slope land. J Soil Water Conserv 5(2):23–29

Xu XH, Wang YB, Liu MY et al (2002) Technology and application of slope protection by plants for river levees. Soil Water Conserv Chin 1:17–18

Yi CQ (1995) The ecological function, protection and utilization of land/water ecotones. Acta Ecol Sin. 15(3):331–336

Young RA (1989) A non-point source pollution model for evaluating agricultural watershed. J Soil Water Conserv 44(2):168–173

Yuan YL, Sun H, Tang Y (2000) A preliminary study of economic characters of mulberry intercropped with contour hedgerows. Ecol Agr Res 8(2):69–71

Zhang JF, Fang MY, Li S et al (2007) Developing agroforestry in slope lands to combat non-point source pollution in China. Chin For Sci Tech 6(4):67–72

Zhang JF, Qin GH (2007) Poplar-based agro-forestry in China and its economic analysis. Shandong Science and Technology Press, Jinan, pp 3–12

Zhang JF, Sun QX (2005) Review on agroforestry systems in China. Chin For Sci Tec. 4(3):80–84

Zhang WL, Wu SX, Ji HJ et al (2004) Estimation of Agricultural Non-point Source pollution in China and the Alleviating Strategies. Sci Agr Sin 37(7):1008–1017

Zhao YX, Liu SH, Zhang X (2007) The agricultural non-point pollution and measures of prevention and control. Inner Morg Envir Sci. 19(1):9–12

Zhong B, Tang ZC (2001) Soil and water loss and its control in three gorges region. Res Soil Water Conserv. 8(2):147–149

Zhong Y (2004) Buffers building technology for America soil conservation. Chin Water Res. 10:63–65

Chapter 10
Purification of Eutrophicated Water and Dynamic Kinetics of Nitrogen Absorption by 2 *Salix integra* Clones

Abstract In this study, we assessed the N and P absorption of 2 *Salix integra* clones in artificial eutrophicated water based on the method of pot experiment, and further conducted the study on NH_4^+–N and NO_3^-–N uptake kinetics. The results showed that 2 *Salix integra* clones could effectively remove TN (90 %) at the treatment level of low concentrations, which was 2 times as that of high concentrations treatment. While for removal efficiency of total phosphorus (TP), at the treatment level of low concentrations it reached 80 %, and then at high concentrations it attained 90 %. The order of removal efficiency was *S. integra* "Yizhibi" > *S. integra* "Weishanhu." Moreover, the removal efficiency of NH_4^+–N and NO_3^-–N was both increased as the concentration changed. For the maximum absorption efficiency and affinity, generally speaking, *S. integra* "Weishanhu" was greater than *S. integra* "Yizhibi" in the state of single N source. However, when the other N source existed, the maximum absorption efficiency would fall down to 50 %.

Keywords *Salix integra* · TN · TP · NH_4^+–N · NO_3^-–N · Eutrophicated water · Absorption · Dynamic kinetics · Clone · Purification

Water eutrophication is a global environmental problem. It not only can lead to water losing their functions, but also destroy water ecological environment and influence the economic construction and social development. Since 1960s, water eutrophication has been regarded as the global water pollution problem (Peng and Chen 1988). Nitrogen and phosphorus pollution is a major factor resulted from water eutrophication (Fang et al., 2010). Studies show that non-point source pollution is a main input form of water nitrogen and phosphorus. Among them, 60 % TN and 30 % Total phosphorus (TP) both come from agricultural non-point sources pollution (Lai et al. 2005; Li and Yang 2004; Zhou et al. 2010). Because non-point source pollution owns disparity and randomness and is not easy to be monitored, traditional treatment methods of point source pollution are not suitable for combating non-point source pollution fundamentally. Thus, it is urgent to seek for an easier, more universal, and long-time effective treatment method. Phytoremediation of nitrogen and phosphorus pollution is characterized with high efficiency, low

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costs, and good landscape effects, and also it is beneficial to recover and rebuild ecosystem (Chen 1996; Zeng et al. 2010; Zhou et al. 2007). However, at present, studies on nitrogen and phosphorus remediation of eutrophic water most focused on wetland herbaceous aquatic plants while few researches are on the restoration of forest and other large-scale woody plants application on polluted water (Chang et al. 2008; Cheng et al. 2010; Zhou et al. 2008). Studies on the absorption kinetics of root system nutrient ions started from the study of Epstein and Hagen at the beginning of 1950s, which applied kinetics of enzyme-catalyzed reactions to the experiments on ion absorption of plants (Bulter 1953). In recent years, researches on the absorption kinetics of seedling roots have been more and more at home and abroad, but most of them focus on the absorption and utilization of crops and forests on the applied chemical fertilizers and other nutrient substances (Zhang et al. 2003, 2004; Wei et al. 2010). However, studies on water quality purification are very few.

S. integra belongs to woody plants and grows fast with large biomass. There are studies pointing out that it had a close correlation between the removal efficiencies of water nitrogen and phosphorous and plant biomass (Jin et al. 2010). Besides, *S. integra* owns graceful form and good landscape effect. With developed root system, it also possesses strong adaptability, fast growth rate, high input–output ratio, superb purification effects on air, as well water pollution. *Salix integra* likes being wet and has strong water resistance; so it is usually planted along the water and has good remediation effects on nitrogen and phosphorous pollution in water (see Figs. 10.1 and 10.2). Therefore, it is an important tree species for environmental protection and restoration (Lin et al. 2009; Shi et al. 2010).

Fig. 10.1 Willows are planted around the pond in Yixing (photograph taken by Jianfeng Zhang)

Fig. 10.2 Willows are planted along the river bank in Yixing (photograph taken by Jianfeng Zhang)

This research selected two 2 common *S. integra* clones in Taihu Lake basin, *S. integra* "Yizhibi" and *Salix integra "*Weishanhu" as experimental materials, and studied its absorption and purification effects on nitrogen and phosphorous in eutrophic water. Furthermore, their absorption kinetics characteristics of ammonium nitrogen and nitrate nitrogen in nutrient solutions of different concentrations and the mutual influence mechanism of different nitrogen forms were explored, which hopefully provided theoretical basis for the ecological remediation of water and soil pollution and other degraded environment problems.

10.1 Materials and Methods

10.1.1 Experimental Materials

This experiment selected *S. integra* clones introduced from Linyi in Shandong Province and then they were bred in Xinsha Island Nursery in Fuyang, Zhengjian Province. *S. integra* branches were cut into 10 cm long cuttings and then evenly put in 40 cm × 20 m bellyboard, with 20 cuttings for each one. Later, they were placed in 40 cm × 20 m × 15 cm plastic box for culture (see Figs. 10.3 and 10.4). Hoagland culture solution was used, with ingredients of 2.00 mmol L^{-1} $Ca(NO_3)\cdot 4H_2O$, 0.10 mmol L^{-1} KH_2PO_4, 0.50 mmol L^{-1} $MgSO_4\cdot 7H_2O$, 0.10 mmol L^{-1} KCl, 0.70 mmol L^{-1} K_2SO_4, 10.00 μmol L^{-1} H3BO3, 0.50 μmol L^{-1} $MnSO_4\cdot H_2O$, 1.0 μmol L^{-1} $ZnSO_4\cdot 7H_2O$, 0.20 μmol L^{-1} $CuSO_4\cdot 5H_2O$, 0.01 μmol L^{-1} $(NH_4)_6Mo_7O_{24}$, 100 μmol L^{-1} Fe-EDTA (Hoagland and Arnon 1950). In the open

Fig. 10.3 Willow cuttings are cultivated for experiments (photograph taken by Ying Wang)

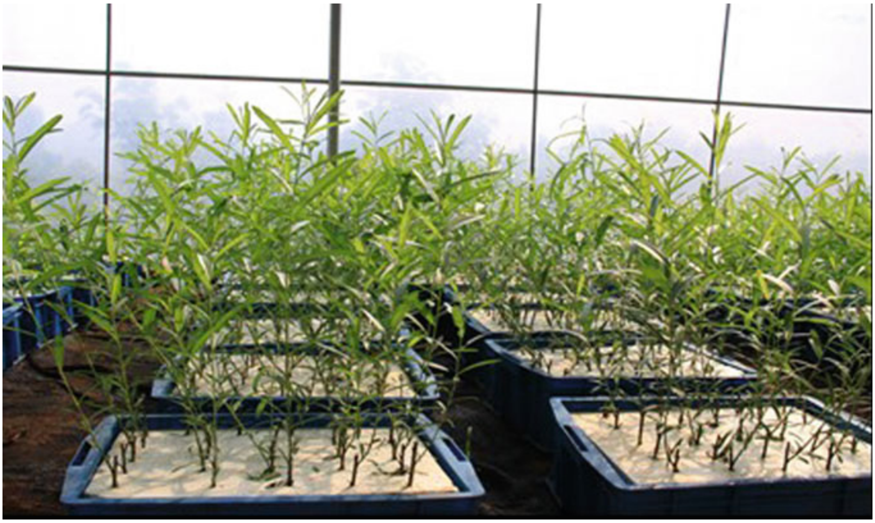

Fig. 10.4 Willow cuttings grow (photograph taken by Ying Wang)

house, 24-h (hour) ventilation was kept, and the culture solution was replaced every 7d (day), keeping the solution pH around 6.5. Under the conditions of natural temperature and with illumination intensity of 9000–14,000 Lx and 10 h illumination every day, *S. integra* grew for 3 months. Afterwards, seedlings of fine and growth consistently were selected and washed by running water. Later, they were washed by distilled water and sucked dry, and then placed in deionized water to cultivate. After a week, they would be in starvation state of nitrogen and phosphorous. Water purification test was carried out.

10.1.2 Purification Efficiency of Willows on Nitrogen and Phosphorous

10.1.2.1 Preparation of Treatments

Simulated eutrophic water was prepared on the basis of Hoagland culture solution. According to the Water quality classification standard in *People's Republic of China Ground Surface Environment Quality Standards* (GB3838-2002), eutrophic water was set at two different concentration levels, and their nutrient concentrations, respectively, were as follows: TN of 1.0–1.5 mg L^{-1}, TP of 0.2–0.3 mg L^{-1}, NH_4^+–N of 1.0–1.5 mg L^{-1}, NO_3^-–N of 0.25–0.4 mg L^{-1} for low concentration (III class water); and TN of 12.0–13.0 mg L^{-1}, TP of 1.0–2.0 mg L^{-1}, NH_4^+–N of 19.0–20.0 mg L^{-1}, NO_3^-–N of 9.0–10.0 mg L^{-1} for low concentration (V class water). Eutrophic water was prepared by adding KNO_3, (NH_4) SO_4, and KH_2PO_4 in purified water.

10.1.2.2 Purification of Nitrogen and Phosphorous in Eutrophic Water

At first, *S. integra* "Yizhibi" and *S. integra* "Weishanhu" growing consistently were selected as experimental plantlets. They were washed with distilled water (not harming root system), air-dried for 10 min, and weighed. Then, 20 kg treated water (eutrophic water) was added in 20L blue rectangle plastic box and 12 cleaned *S. integra* seedlings were placed in it. Control tests of treated water at each concentration were performed, namely, with the same treated water while no willow seedlings planted. The experiment continued for 4 weeks, water samples were taken every 7 days, and water in the plastic box was weighed to convert the total amounts of TN, TP, NH_4^+–N and NO_3^-–N and water loss. Each treatment sample was collected and measured three times.

On the day of water sample measurement, TN and NO_3^-–N were measured by ultraviolet spectrophotometry, TP was measured by Mo-Sb Anti-spectrophotometer, and NH_4^+–N was measured by Nessler's reagent spectrophotometry (Wei and State Environmental Protection Administration 2002), similarly hereinafter. The calculation formula of the removal efficiency of nitrogen and phosphorus can be expressed as, Removal efficiency:

$$\% = (C_0 \cdot V_0 - C_i \cdot V_i)/(C_0 \cdot V_0)$$

where C_0 is the initial concentration, $V_0$is the initial volume, and C_i is the water volume at day *i*.

10.1.3 Measurement of Different Forms of Nitrogen

10.1.3.1 Absorption Kinetics of NH_4^+–N

The experiment adopted ion depletion curve method (Claassen and Barber, 1974; Zhang et al. 2003). Preparation of absorption solution: (1) Absorption solution was prepared by analytically pure NH_4Cl and 0.2 mmol L^{-1} $CaSO_4$. The concentration of NH_4Cl was set at 8 levels, 0.08, 0.1, 0.2, 0.4, 0.8, 1, 2, and 4 mmol L^{-1}. (2) The seedlings prepared were set 3 strains of a group and after cleaning they were dried and, respectively, placed into conical flask with absorption solution (shade the root with black plastic bags). The solution volume is set 500 ml, with pH of 6.5. Then, it was placed in an artificial climate box for 12 h, with temperature of 25 °C, humidity of 75 %, and light intensity of 8000Lx. Later, residual ammonium nitrogen in the solution was measured, and difference method was used to calculate absorption capacity and absorption efficiency [mmol/(g.FW.h)] in fresh weight (FW).

10.1.4 Absorption Kinetics of NO_3^-–N

The absorption solution was prepared with analytically pure KNO_3 and 0.2 mmol L^{-1} $CaSO_4$. The concentration of KNO_3 was set at 8 levels, 0.08, 0.1, 0.2, 0.4, 0.8, 1, 2, and 4 mmol L^{-1}. The other procedures are similar to those done in the absorption kinetics test of NH_4^+.

10.1.4.1 Influences of NH_4^+–N on the Absorption of NO_3^-–N

The absorption solution was prepared with analytically pure NH_4Cl, KNO_3, and 0.2 mmol L^{-1} $CaSO_4$. The concentration of KNO_3 was set at 10 levels, 0.02, 0.04, 0.08, 0.1, 0.2, 0.4, 0.8, 1, 2, and 4 mmol L^{-1}. The concentration of NH_4Cl was set as 1 mmol L^{-1}. And pH was set 6.5. Each group was set with 3 parallel repetitions. The absorption experiment is similar to the above described (see Sect. 10.1.3.1).

10.1.4.2 Influences of NO_3^-–N on the Absorption of NH_4^+–N

The concentration of NH_4Cl in the absorption solution was set at 10 levels, 0.02, 0.04, 0.08, 0.1, 0.2, 0.4, 0.8, 1, 2, and 4 mmol L^{-1}. The concentration of KNO_3 was set as 1 mmol L^{-1}. The supporting liquid was 0.2 mmol L^{-1} $CaSO_4$. The absorption experiment is similar to the above described (see Sect. 10.1.3.1).

After plants were taken out from the incubator, absorbent paper was used to immediately dry the water on the surface. The roots of willow were put in 75 °C drying oven to dry until their weight was constant. Then their weights were measured, as well as the contents of NH_4^+–N and NO_3^-–N in the nutrient solution. Difference method was used to calculate the changes in their concentration and the net absorption efficiency of N in unit dry weight in unit time. Hofstee conversion formula of Michaelis-Menten equation was used to possess data, solving kinetic parameter V_{max} (maximum absorption rate) and K_m (apparent Michaelis-Menten constant). In Michaelis-Menten equation, $\upsilon = V_{max}[S]/(K_m + [S])$, $[S]$ is solution concentration, υ is the absorption efficiency; K_m is Michaelis-Menten constant, which is the external liquid concentration at $1/2V_{max}$, reflecting the affinity between the active centers of carrier and ion. The smaller the K_m is, the higher the affinity is. V_{max} is the maximum absorption efficiency, which is relevant to the carrier number and the operation efficiency of carriers. The greater the V_{max} is, the higher internal absorption potential is.

All the data in the experiment were processed and analyzed by Origin7.0 and Spss18.

10.2 Results and Analysis

10.2.1 Purification Effect of S. integra

10.2.1.1 Removal Efficiency of *S. integra* on TN

The removal efficiency of different willow clones on TN in polluted water is shown as Table 10.1. It can be seen from Table 10.1 that the removal efficiency of willows on TN in simulated low-concentration polluted water is superior to that in simulated high-concentration polluted water. In simulated low-concentration polluted water, the removal efficiency of *Salix integra* "Weishanhu" and *Salix integra* "Yizhibi" both can reach 100 % after treatment of 2 weeks. What is different is that the concentration of TN treated by *Salix integra* "Yizhibi" later increased a little. In simulated high-concentration polluted water, the removal efficiency of *Salix integra* "Yizhibi" on TN is slightly higher than that of *Salix integra* "Weishanhu." In particular, in first week the removal efficiency of *Salix integra* "Yizhibi" reached 8.7 %, which is 22 times higher than that of *Salix integra* "Weishanhu." After two weeks, the removal efficiency of *Salix integra* "Weishanhu" increased obviously,

Table 10.1 Removal efficiency of *salix integra* clones on TN

Measuring item	Treatment time (*d*)	*Salix integra* "Yizhibi" (low concentration)	*Salix integra* 'Weishanhu" (low concentration)	*Salix integra* "Yizhibi" (high concentration)	*Salix integra* "Weishanhu" (high concentration)
Total nitrogen in water (mg L^{-1})	0	2.301 ± 0.064^{a}	2.559 ± 0.529^{a}	13.865 ± 0.083^{a}	13.779 ± 0.034^{a}
	7	2.030 ± 0.477^{a}	0.670 ± 0.078^{b}	12.664 ± 0.136^{b}	13.718 ± 0.157^{a}
	14	0^{b}	0^{c}	7.081 ± 0.087^{c}	8.416 ± 0.006^{b}
	21	0.223 ± 0.033^{b}	0^{c}	4.544 ± 0.057^{d}	6.481 ± 0.202^{c}
Removal efficiency (%)	7	11.8	73.8	8.7	0.4
	14	100	100	48.9	38.9
	21	90.3	100	67.2	53.0

Note The different normal letters indicate significant difference at level 0.05 among different treatment time. The same as below while was still lower than that of *Salix integra* "Yizhibi," which was 48.9 %. After three weeks, the experiment is over, and the removal efficiency of *Salix integra* "Weishanhu" reached 53.0 %, while for that of *Salix integra* "Yizhibi" was 67.2 %.

10.2.1.2 Removal Efficiency of *S. integra* on TP

It can be seen from Table 10.2 that no matter how high the initial TP concentration is, it will reach a low level through seedlings' absorption. In simulated low-concentration polluted water, the removal efficiency of *Salix integra* "Yizhibi" on TP reaches 93.2 %, which is far higher than that of *Salix integra* "Weishanhu," the value 68.1 %. This may be that *Salix integra* "Yizhibi" after starvation treatment has a huge demand on P. Later, with the TP concentration increasing at 0.09 mg L^{-1}, the removal efficiency at 3rd week gradually increased, reaching 82.4 %, which is higher than that of *Salix integra* "Weishanhu," which is 79.9 %. In simulated high-concentration polluted water, the removal efficiency of *Salix integra* "Yizhibi" and *S. integra* "Weishanhu" is both higher than that in simulated low-concentration polluted water. The TP concentration of *Salix integra* "Yizhibi" finally is only 0.070 mg L^{-1}, the removal efficiency reaching 96.1 %; and the TP concentration of *Salix integra* "Weishanhu" finally falls to only 0.142 mg/L, the removal efficiency going up to 91.7 %.

10.2.1.3 Removal Efficiency of *Salix Integra* on NH_4^+–N

It can be seen from Table 10.3 that the removal efficiency of 2 willow clones on NH_4^+–N differs between simulated low-concentration polluted water and simulated high-concentration polluted water. In simulated low-concentration polluted water, the removal efficiency of *Salix integra* "Yizhibi" and *Salix integra* "Weishanhu," respectively, is 72.7 and 79.4 % and in the 3-week experiment, it

Table 10.2 Removal efficiency of *Salix integra* clones on TP

Measuring Item	Treatment time (*d*)	*Salix integra* "Yizhibi" (low concentration)	*Salix integra* "Weishanhu" (low concentration)	*Salix integra* "Yizhibi" (high concentration)	*Salix integra* "Weishanhu" (high concentration)
Total nitrogen in water (mg L^{-1})	0	0.259 ± 0.012^{a}	0.254 ± 0.015^{a}	1.774 ± 0.048^{a}	1.715 ± 0.009^{a}
	7	0.018 ± 0.003^{b}	0.081 ± 0.005^{b}	0.282 ± 0.122^{b}	1.386 ± 0.008^{b}
	14	0.090 ± 0.009^{c}	0.071 ± 0.005^{b}	0.225 ± 0.008^{b}	0.862 ± 0.012^{c}
	21	0.046 ± 0.008^{b}	0.051 ± 0.005^{b}	0.070 ± 0.004^{c}	0.142 ± 0.008^{d}
Removal Efficiency (%)	7	93.2	68.1	84.1	19.2
	14	65.1	72.0	87.3	49.7
	21	82.4	79.9	96.1	91.7

Table 10.3 Removal efficiency of *Salix integra* clones on NH_4^+–N

Measuring item	Treatment time (*d*)	*Salix integra* "Yizhibi" (low concentration)	*Salix integra* "Weishanhu" (low concentration)	*Salix integra* "Yizhibi" (high concentration)	*Salix integra* "Weishanhu" (high concentration)
Total nitrogen in water (mg L^{-1})	0	2.647 ± 0.036^a	2.592 ± 0.045^a	19.483 ± 0.066^a	19.392 ± 0.294^a
	7	0.597 ± 0.044^c	0.501 ± 0.035^b	6.331 ± 0.004^b	9.992 ± 0.025^b
	14	0.587 ± 0.012^c	0.552 ± 0.004^b	1.230 ± 0.039^c	6.130 ± 0.089^c
	21	0.722 ± 0.017^b	0.533 ± 0.017^b	0.782 ± 0.022^d	2.957 ± 0.105^d
Removal efficiency (%)	7	77.4	80.7	67.5	48.5
	14	77.8	78.8	93.7	68.4
	21	72.7	79.4	96.0	84.8

Table 10.4 Removal efficiency of *Salix integra* clones on NO_3^-–N

Measuring item	Treatment time (*d*)	*Salix integra* "Yizhibi" (low concentration)	*Salix integra* "Weishanhu" (low concentration)	*Salix integra* "Yizhibi" (high concentration)	*Salix integra* "Weishanhu" (high concentration)
Total nitrogen in water (mg L^{-1})	0	0.356 ± 0.007^c	0.358 ± 0.011^a	9.845 ± 0.007^a	9.871 ± 0.007^a
	7	0.242 ± 0.012^d	0.237 ± 0.026^c	8.605 ± 0.037^b	9.522 ± 0.005^b
	14	0.515 ± 0.014^b	0.220 ± 0.005^c	7.081 ± 0.087^c	8.416 ± 0.006^c
	21	0.592 ± 0.005^a	0.304 ± 0.004^b	4.666 ± 0.057^d	7.048 ± 0.007^d
Removal efficiency (%)	7	32.2	33.8	12.6	3.5
	14	−44.5	38.6	28.1	14.7
	21	−66.2	15.1	52.6	28.6

increased temporarily. In simulated high-concentration polluted water, the removal efficiency of *Salix integra* "Yizhibi" is 96.0 %, obviously higher than that of *Salix integra* "Weishanhu," which is 84.8 %. Moreover, the removal efficiency of 2 *Salix integra* increases all the time. It can be predicted that with the time going on, the removal efficiency will keep increasing.

10.2.1.4 Removal Efficiency of *S. integra* on NO_3^-–N

The removal efficiency of 2 *Salix integra* on NO_3^-–N is not so ideal. In simulated low-concentration polluted water, anti-absorption occurs in *Salix integra* "Yizhibi" and after 3-week experiment, its removal efficiency is −66.2 %, and the removal efficiency of *Salix integra* "Weishanhu" also is low, only reaches 15.1 %. In simulated high-concentration polluted water, the removal efficiency of *Salix integra* "Yizhibi" is 52.6 % and that of *S. integra* "Weishanhu" is 28.6 %. Thus, it can be seen that *Salix integra* has good removal efficiency on high-concentration NO_3^-–N (see Table 10.4).

10.2.2 Absorption Kinetics of S. integra *on Different Forms of Nitrogen*

10.2.2.1 Absorption Kinetic Characteristics of *S. integra* on NH_4^+–N

The experiment results indicate that under the condition of single nitrogen source, the absorption efficiency of *S. integra* on NH_4^+–N and NO_3^-–N in different growth stages is different with the concentration changes in NH_4^+–N and NO_3^-–N which conforms to Michaelis-Menten equation. After the fitting of Michaelis-Menten equation, we can obtain the maximum absorption efficiency V_{max} and

Table 10.5 Parameters of NH_4^+–N, NO_3^-–N absorption kinetics of different *Salix integra* clones

Willow clones	Form of Nitrogen	V_{max}(mmol g^{-1} root DW h^{-1})	K_m (mmol L^{-1})	R^2
Salix integra "Yizhibi"	NH_4^+–N	0.0998	6.6034	0.9955
	NH_4^+–N (NO_3^-–N)	0.0436	1.7722	0.9953
	NO_3^-–N	0.1095	3.3146	0.9991
	NO_3^-–N (NH_4^+–N)	0.0301	2.3771	0.9846
Salix integra "Weishanhu"	NH_4^+–N	0.1097	5.1743	0.9889
	NH_4^+–N (NO_3^-–N)	0.0558	6.4522	0.9912
	NO_3^-–N	0.1101	2.3351	0.9856
	NO_3^-–N (NH_4^+–N)	0.1236	4.2247	0.9915

Michaelis–Menten constant K_m of 2 *Salix integra* on NH_4^+–N and NO_3^-–N (as shown in Table 10.5, DW means dry weight).

It can be seen from Figs. 10.5 and 10.6 that with the increase in the concentration of NH_4^+–N in the solution, the absorption efficiency of *Salix integra* on NH_4^+–N rises continuously. However, Fig. 10.3 shows that in the presence of NO_3^-–N, the absorption efficiency of *S. integra* on NH_4^+–N gradually tends to saturate. The absorption efficiency of different *Salix integra* on NH_4^+–N varies to certain extent. In the treatment of 100 % NH_4^+–N, the maximum absorption efficiency (V_{max}) of 2 *Salix integra* on NH_4^+–N has no significant difference, with K_m of *S. integra* "Yizhibi" of 6.6034 mmol L^{-1}, which is slightly higher than that of *Salix integra* "Weishanhu," 5.1743 mmol L^{-1}. Namely, the NH_4^+–N affinity of

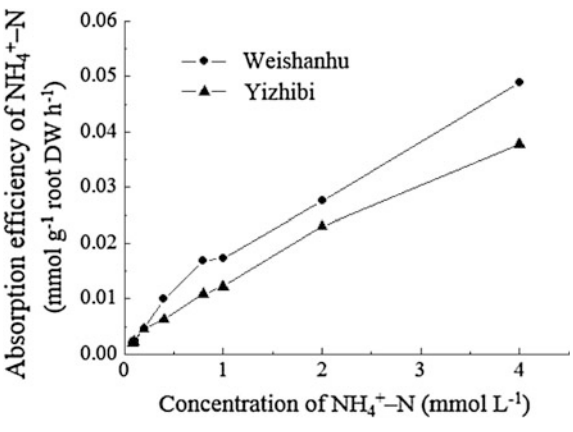

Fig. 10.5 NH_4^+–N absorption efficiency by different *Salix integra* clones

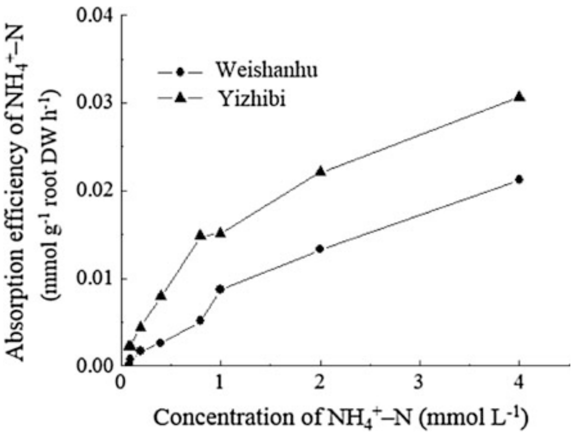

Fig. 10.6 NH_4^+-N absorption efficiency by different *Salix integra* clones in the presence of NO_3^-–N

Salix integra "Yizhibi" is slightly higher than that of *Salix integra* "Weishanhu." When there exists NO_3^-–N, the maximum absorption efficiency of *S. integra* "Yizhibi" decreases by 56 %, and that of *Salix integra* "Weishanhu" decreases by 49 %. Thus, it can be seen that the presence of NO_3^-–N can seriously influence the absorption efficiency of *Salix integra* on NH_4^+–N. At this time, the K_m of *Salix integra* "Yizhibi" decreases to 1.7722 mmol L^{-1}, while the K_m of *Salix integra* "Weishanhu" increases to 6.4522 mmol L^{-1}, showing significant difference, which indicates that the affinity of *Salix integra* "Yizhibi" is better than that of *Salix integra* "Weishanhu."

10.2.2.2 Absorption Kinetic Characteristics of *Salix Integra* on NO_3^-–N

It can be seen from Figs. 10.7 and 10.8 that the absorption efficiency of *Salix integra* on NO_3^-–N increases with the increase in NO_3^-–N concentration in the solution and *S. integra* "Weishanhu" is always higher than *S. integra* "Yizhibi." When the solution purely contains NO_3^-–N, the maximum absorption efficiency of *Salix integra* "Yizhibi" and *S. integra* "Weishanhu," respectively, is 0.1095 mmol g^{-1} root DW h^{-1} and 0.1101 mmol g^{-1} root DW h^{-1}, which shows no significant difference. However, the K_m of *Salix integra* "Yizhibi" is 29 % higher than that of *S. integra* "Weishanhu," which indicates that the NO_3^-–N affinity of *Salix integra* "Yizhibi" is inferior to that of *S. integra* "Weishanhu." In the presence of NH_4^+–N, the maximum absorption efficiency of *Salix integra* "Yizhibi" on NO_3^-–N decreases dramatically to 0.0301 mmol g^{-1} root DW h^{-1}, so does its affinity, with K_m of 2.3771 mmol L^{-1}. However, the maximum absorption efficiency of *Salix integra* "Weishanhu" increases to 0.1236 mmol g^{-1} root DW h^{-1}, with slight increase in K_m

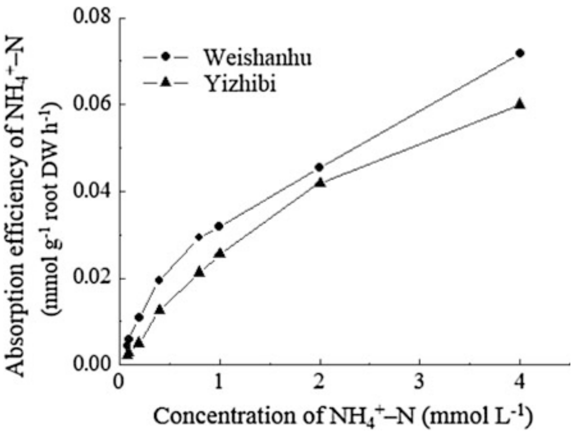

Fig. 10.7 Absorption efficiency of different *Salix integra* clones on NO_3^-–N

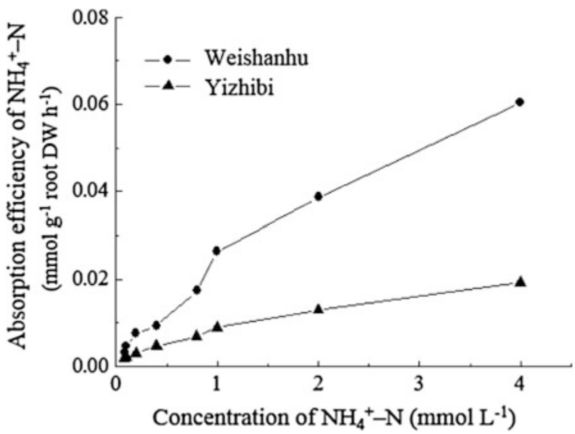

Fig. 10.8 Absorption efficiency of different *Salix integra* clones on NO_3^-–N in the presence of NH_4^+–N

of 4.2247 mmol L^{-1}. These indicate that the presence of NH_4^+–N will promote the absorption efficiency of *Salix integra* "Weishanhu" on NO_3^-–N.

10.3 Discussion and Conclusions

Salix integra owns certain removal efficiency on the nutrient substance in simulated polluted water, especially TN and TP. Also the removal efficiency of *S. integra* "Yizhibi" on TN and TP is superior to that of *S. integra* "Weishanhu." Among them, the removal efficiency of *S. integra* "Yizhibi" on low-concentration TN reaches 90.3 %, while that of *S. integra* "Weishanhu" is higher, reaching 100 %. For high-concentration TN, the removal efficiency of both decreases slightly, respectively is 67.2 % and 53.0 %. In terms of purification of TP, the removal efficiency of 2 *Salix integra* clones on high-concentration TP is better than that on low-concentration TP. The removal efficiency of *S. integra* "Yizhibi" and *S. integra* "Weishanhu" on low-concentration TP, respectively, is 82.4 and 79.9 %, while that on high-concentration TP, respectively, is 96.1 and 91.7 %. This study finds that the removal efficiency of 2 *S. integra* on NH_4^+–N is obviously higher than that on NO_3^-–N. Contrary to TN, the removal efficiency of 2 clones on high-concentration is better than that on low-concentration. The removal efficiency of 2 clones on NO_3^-–N is not ideal. In simulated low-concentration polluted water of NO_3^-–N, anti-absorption even occurs in the presence of *S. integra* "Yizhibi," with removal efficiency of −66.2 %. There are two possible reasons: One is that the temperature in summer is so high that it is easy for NH_4^+–N to have nitrification and generate NO_3^-–N; the other one is that when the concentration of external NO_3^-–N is overly low, plants will release NO_3^-–N. However, the specific process in not clear, which needs further study.

Obviously the function of different plant species and different genotypes of the kindred plant usually varies a lot on absorption of nutrient ions (Chang et al. 2008; Dang et al. 2004; Zhang et al. 2003). Different absorption and transportation ways of NH_4^+–N and NO_3^-–N in plants are the important foundation for the absorption kinetics changes in root system (Cheng et al. 2010; Wang et al. 2011). For plants, the transportation systems of NH_4^+–N and NO_3^-–N have various types such as high affinity, low affinity, and both high and low affinity, which are closely relevant to the external ion concentration and gene expression (Aalan et al., 1992; Forde and Clarkson 1999; Siddiqi et al. 1990). The research results in this chapter demonstrate that in case of single nitrogen source, the maximum absorption efficiency of two genotype clones of *S. integra* on NH_4^+–N and NO_3^-–N has no significant difference, and the different forms of nitrogen affinity of *Salix integra* "Weishanhu" are slightly higher than those of *S. integra* "Yizhibi." When there exist other nitrogen sources, the absorption efficiency of 2 clones on NH_4^+–N and NO_3^-–N decreases by nearly 50 %. The possible reason may be that the presence of other ions influences the genetic expression of carrier protein synthesis that controls nitrogen, which further decreases the total carrier protein on cytomembrane, or influences the surrounding environment of carrier on cytomembrane (Crawford and Glass 1998; Colmer and Bloom 1998; Wei et al. 2010), which further inhibits the absorption of *S. integra* root system on nitrogen source. It may also lie in that the addition of other nitrogen sources in the nutrient solution changes the pH value of the original solution, which further decreases the absorption of *Salix integra* on nitrogen. At the same time, this experiment also find that the absorption curves of 0–4 mmpl L^{-1} NH_4^+–N and NO_3^-–N did not tend to be flat due to absorption saturation. This may be because *Salix integra* belongs to woody plant and its absorption efficiency on NH_4^+–N and NO_3^-–N is high.

In conclusion, 2 *Salix integra* clones both have certain restoration effects on water eutrophication. When the water pollution is serious, firstly pioneer plants can be used to remove nutrients. Then, *Salix integra* can be planted for long-term purifying water quality (see Figs. 10.9 and 10.10). Researches indicate that *Salix*

Fig. 10.9 Willows grow as wetland plants (photograph taken by Jianfeng Zhang)

Fig. 10.10 Willows grow along lake shore in Nanjing (photograph taken by Jianfeng Zhang)

integra clones not only have certain remediation effects on water eutrophication but also have specific bioremediation effects on water and soil pollution by heavy metals (Ali et al. 2003; Xu et al. 2007). Planting *Salix integra* along water banks can realize win-win benefits in economy and environment. Therefore, *S. integra* is an optimal tree species for water environmental protection and bioremediation.

References

Ali M, Vajpayee P, Tripathi R, et al (2003) Phytoremediation of lead, nickel, and copper by *Salix acmophylla* Boiss: role of antioxidant enzymes and antioxidant substances. Bull Environ Cont Toxicol 70(3):462–469

Bulter G (1953) Ion uptake by young wheat plants. III. Phosphate absorption by excised roots. Physiol Plant 6(4):637–661

Chang HQ, Li N, Xu XF (2008) NH_4^+ and NO_3^- uptake kinetics of three aquatic macrophytes. Ecol Envir 17(2):511–514

Chen JQ (1996) Riparian vegetation characteristics and their role in ecosystem and landscape. Chin J Appl Ecol 7(4):439–448

Cheng LW, Zou DH, Zheng QS et al (2010) Effects of temperature and light intensity on the nitrate uptake kinetics of nitrogen starved and replete ulvalactuca. Chin J Ecol. 29(5):939–944

Claassen N, Barber SA (1974) A method for characterizing the relation between nutrient concentration and flux into roots of intact plants. Plant Physiol 54(4):564–568

Colmer T, Bloom A (1998) A comparison of NH_4^+ and NO_3^- net fluxes along roots of rice and maize. Plant Cell Environ 21(2):240–246

Crawford NM, Glass ADM (1998) Molecular and physiological aspects of nitrate uptake in plants. Trends Plant Sci 3(10):389–395

Dang C, Shen Q, Wang G (2004) Tomato growth and organic acid changes in response to partial replacement of NO_3^-–N by NH_4^+–N. Pedosphere 14(2):159–164

Fang YX, He CQ, Liang X et al (2010) The purigying effect of polluted water by the aquatic plants. J Hydroecol 3(6):36–40

Forde BG, Clarkson DT (1999) Nitrate and ammonium nutrition of plants: physiological and molecular perspectives. Adv Bot Res 30:1–90

Hoagland D, Arnon DL (1950) The water culture method for growing plants without soil. Calif Agric Exp Sta Circ 347:1–32

Jin SQ, Zhou JB, Zhu XL et al (2010) Comparison of nitrogen and phosphorus uptake and water purification ability of ten aquatic macrophytes. J Agro-Environ Sci 29(8):1571–1575

Lai GY, Yu G, Gui F (2005) Simulation assessment on nutrient transport in Taihu Lake Basin. Adv Earth Sci 35(z2):121–130

Li ZY, Yang GS (2004) Research on non-point source pollution in Taihu Lake Region. J Lake Sci 16:83–88

Lin HF, Huang J, Zhu LD et al (2009) Study on the growth characteristic of willow (*Salix babylonica* Linn) planted on floating bed and its purification efficiency in eutrophicated water body. J Hubei Univ (Nat Sci Ed). 31(2):210–212

Peng JX, Chen HJ (1988) Water quality eutrophication and prevention. China Environmental Science Press, Beijing

Shi X, Chen YT, Wu TL et al (2010) Plant growth and metal uptake by seven salix clones on Cu/Zn contaminated environment. Chin Environ Sci. 12:1683–1689

Siddiqi MY, Glass ADM, Ruth TJ (1990) Studies of the uptake of nitrate in barley: I. kinetics of $^{13}NO_3$–influx. Plant Physiol 93(4):1426–1432

Wang YY, Huo YZ, Tian QT et al (2011) NO_3-N and PO_4-P uptake kinetics of enteromorpha. J Shanghai Ocean Univ 20(1):121–125

Wei FS, Administration State Environmental Protection (2002) Editorial board of water and wastewater monitoring analytical mehod. China Environmental Science Press, Beijing

Wei HX, Xu CY, Ma LY et al (2010) Dynamic kinetic characteristics of different forms of nitrogen absorbed by *Larix olgensis* seedling. Plant Nut Fert Sci 16(2):407–412

Xu AC, Chen YT, Wang SF et al (2007) Changes of physiological characteristic of five salix clones under cadmium stress. Ecol Environ 16(2):41

Zeng LX, Huang ZL, Xiao WF et al (2010) Function, design and management of riparian vegetation buffer strips. For Sci 46(2):128–133

Zhang HC, Wang GP, Xu XZ et al (2003) Phosphate uptake characteristics of H_2PO_4-kinetics and phosphorus efficiency in clones of poplar. For Sci 39(6):40–46

Zhang YL, Dong YY, Shen Q, et al (2004) Characteristics of NH_4^+ and NO_3^- Uptake by rices of different genotypes. Acta Pedol Sin 41(6):918–923

Zhou XH, Wang GX, Yang F et al (2008) Uptake kinetic characteristics of different ammonium and nitrate by ipomoca aquatica forsk. Res Soil Water Conserv 15(5):84–87

Zhou XP, Xu XF, Wang JG et al (2007) Nitrogen and phosphorus removal performance by three planted floats in eutrophic water bodies in winter. Chin J Eco-Agr 15(004):102–104

Zhou YR, Yuan XY, Wang JR et al (2010) Screening duckweed (Lemnaceae) species for efficient removal of water-body's nitrogen in the Tai Lake Region and preliminary study on nitrogen removal mechanism. Acta Pedol Sin 3:390–397

Chapter 11
Physiological Characteristics and Nitrogen Absorption/Distribution Features of *Salix matsudana* Under Different Nitrogen Stresses

Abstract This chapter discusses the growth, nitrogen absorption/distribution, and physiological responses of *Salix matsudana* seedlings cultured in hydroponic solution with different nitrogen sources ammonium nitrogen ($NH_4{}^+$–N) or nitrate nitrogen ($NO_3{}^-$–N)); inadequate, medium, high, or excessive nitrogen. Results showed that *S. matsudana* biomass increased with increasing nitrogen concentration to a certain extent. *S. matsudana* growth was inhibited by excessive nitrogen concentration, and the inhibition rate of $NH_4{}^+$–N was higher than that of $NO_3{}^-$–N. *S. matsudana* showed absorption preference toward $NH_4{}^+$–N than $NO_3{}^-$–N under the same nitrogen concentration. at.% content, ^{15}N absorption, and Ndff% exhibited the following trend in different organs of *S. matsudana*: root > stem > leaf. Moreover, $NH_4{}^+$–N content was higher than that of $NO_3{}^-$–N, and the difference intensified with increasing nitrogen concentration. Excessive and inadequate nitrogen concentrations of $NH_4{}^+$–N and $NO_3{}^-$–N exerted different effects on physiological parameters in roots and leaves. Root activity under excessive concentrations of $NH_4{}^+$–N and $NO_3{}^-$–N decreased by 50.61 % and increased by 19.53 %, respectively, compared with that of the control group. Root length, root surface area, average root diameter, root volume, and root tips were lower by 30.92, 29.48, 19.44, 27.01 and 36.41 %, respectively, in $NH_4{}^+$–N treatment and by 1.66, 5.65, 1.49, 5.06, and 25.72 %, respectively, in $NO_3{}^-$–N treatment than those in the control group. This result indicated that high $NH_4{}^+$–N concentrations elicited stronger stress effect on *S. matsudana* than $NO_3{}^-$–N. Therefore, the effect of $NH_4{}^+$–N on *S. matsudana* could be alleviated to some extent by adding $NO_3{}^-$–N to improve the remediation of water polluted by nitrogen.

Keywords ^{15}N tracer technique · *Salix matsudana* · Ammonium nitrogen · Nitrate nitrogen · Absorption and distribution · Physiological characteristics

Water pollution caused by nitrogen remains prevalent worldwide because of global climate changes, irrational human activities, and intensified atmospheric nitrogen deposition (Erisman et al. 2008). Atmospheric nitrogen deposition and excessive

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Fig. 11.1 The aquatic and herbaceous plants are planted along Taihu Lake bank (photograph taken by Jianfeng Zhang)

use of nitrates significantly increase the level of soluble nitrogen in water. Water pollution by nitrogen continuously spreads in China (Gao et al. 2004; Liu et al. 2013). Phytoremediation is an environmental amelioration technology that utilizes plants to transfer, accommodate, or convert pollutants to reduce or eliminate contamination (Zhang et al. 2010). This technology is widely applied in research of soil and water pollution remediation because of its high efficiency, economic benefits, and satisfactory landscape effect (Chang et al. 2008; Fang et al. 2008). Most studies mainly focused on eutrophic water restoration, particularly the use of aquatic and herbaceous plants (see Fig. 11.1); however, few studies investigated woody plants (Chang et al. 2008; Fang et al. 2008; Cheng et al. 2010). Willow, which exhibits humid preference, developed root system, strong adaptability, fast growth, and strong water tolerance, is often planted along water banks to obtain good remediation effect on water pollution by nitrogen and phosphorus (see Fig. 11.2). Willow is indeed an important tree species for phytoremediation of eutrophic waters (Chen et al. 2011; Wang et al. 2012).

Fig. 11.2 Willows are planted along riverbanks (photograph taken by Jianfeng Zhang)

11.1 Introduction

Nitrogen (N) is an indispensable component of nucleic acids, proteins, other organic molecules, and their respective catabolites (Huang 2004). However, excessive N levels in the environment affect the physiological characteristics of plants. For example, excessive NH_4^+ concentration affects the growth and physiological characteristics of most plants and alters the contents of mineral elements, organic ions, and amino acids (Ariz et al. 2011a, b). Excessive NH_4^+ or NO_3^- concentration in the root system is toxic to most plants and influences N absorption, accumulation, and distribution in different positions (Ariz et al. 2010). Isotope tracing is a technique wherein tracers, which interact with elements or materials, are added in the organism to determine changes in the element or matter content (Wang et al. 2013). Stable N isotope tracer method reveals the occurrence mechanism of important ecological processes and is thus an important tool in ecological research (Wang et al. 2007). Some researchers reported that ^{15}N tracer technique can elucidate the absorption/distribution mechanism of plants for different nitrogen sources by tagging the features, measurability, and evident differences of ^{15}N compared with common nitrogen (Wang et al. 2008; Lin 2010; Kuang et al. 2011).

In this chapter, plantlet growth, nitrogen absorption/distribution, and physiological responses were evaluated in *Salix matsudana* (willow) seedlings cultured in a hydroponic solution with different nitrogen stresses [ammonium nitrogen (NH_4^+–N) and nitrate nitrogen (NO_3^-–N)]. This study provides theoretical and scientific bases for applications of willow in remediation of water pollution.

11.2 Materials and Methods

11.2.1 Cultivation of Testing Materials

Twenty-seven *S. matsudana* clones were obtained from Shandong Binzhou Yiyi Forestry Co., Ltd., in March, 2013. Willow branches were cut into 10-cm cuttings and placed into several pieces of 40 cm × 20 cm porous cystosepiments, with 12 cuttings in each material. The cystosepiments were placed in 19-L square plastic boxes and cultured at 20–30 °C for about 10 h under natural illumination per day (see Fig. 11.3). The culture medium was improved Hoagland nutrient solution, which comprised the following components: 0.51 g L^{-1} KNO_3^-, 0.82 g L^{-1} $Ca(NO_3)_2 \cdot 4H_2O$, 0.136 g L^{-1} $KH_2PO_4^-$, 0.49 g L^{-1} $MgSO_4 \cdot 7H_2O$, 2.86 mg L^{-1}

Fig. 11.3 Willow seedlings are cultivated (photograph taken by Jianfeng Zhang)

H_3BO_3, 1.81 mg L^{-1} $MnCl_2{\cdot}4H_2O$, 0.22 mg L^{-1} $ZnSO_4{\cdot}7H_2O$, 0.45 mg L^{-1} $(NH_4)_6Mo_7O_{24}$, 0.6 mg L^{-1} $FeSO_4^-$, and 0.744 mg L^{-1}EDTA (Liu et al. 2011). During culture of *S. matsudana* clones, ventilation was sustained 24 h per day, the nutrient solution was replaced every 7 d, and pH 6.5 was maintained. After growing *S. matsudana* seedlings for 3 months, those with fine appearance and uniform growth (height ± <5 cm and biomass ± <10 g) were selected. Height and biomass of the seedlings were measured. The seedlings were rinsed by tap water, cleaned by distilled water, and dried by exposure to the sun for about 10 min. The dried seedlings were placed into deionized water and subjected to nitrogen starvation for 1 week. Nitrogen absorption test was then conducted.

^{15}N (99.99 %) was obtained from the Shanghai Research Institute of Chemical Industry. The treated *S. matsudana* seedlings were placed in 19-L square plastic boxes (eight seedlings in each box for a total of 48 boxes). The seedlings were fixed in plastic boxes by sponge and cystosepiments. Subsequently, 1/4 Hoagland nutrient solution with $CaSO_4$ but without KNO_3 and $Ca(NO_3)_2{\cdot}4H_2O$ was employed to ensure normal growth of *S. matsudana*. Different nitrogen treatments were then established. N and $K^{15}NO_3$ were added in $(^{15}NH_4)_2SO_4$ for NH_4^+–N and NO_3^-–N, respectively. Four nitrogen concentrations were established according to the grading standard of water eutrophication (Wang et al. 2002); treatments included 1.4, 2.8, 7.0, and 28.0 mg L^{-1} nitrogen, which were marked N1 (inadequate nitrogen), N2 (medium nitrogen), N3 (higher nitrogen), and N4 (excessive nitrogen), respectively. The test had eight treatments, and each treatment had two boxes containing 16 seedlings of *S. matsudana*. Each treatment was performed three times. The nutrient solution was changed every 7 d. NH_4^+–N treatment was added with 0.588 mg L^{-1} nitrification inhibitor ($C_2H_4N_4$) (2 mL per box) to prevent the conversion of $^{15}NH_4^+$ into $^{15}NO_3^-$. The entire experiment was performed from March to August 2013 in the greenhouse and laboratory of the Institute of Subtropical Forestry, Chinese Academy of Forestry, Fuyang, Zhejiang. The study area is located 90 m above sea level and experiences subtropical monsoon climate; the area has an annual average temperature of 16.2 °C and a precipitation of 1452 mm.

11.2.2 Experimental Methods

11.2.2.1 Weighing of Plantlet Biomass

Six *S. matsudana* seedlings with complete leaves and root system were collected from each treatment after culture for 28 days. Fresh and dry weights were measured by an electronic balance with 0.01 g sensitivity. Before weighing, the seedlings were cleaned with deionized water in the laboratory. Root, stem, and leaf were separated and air dried. Fresh weight was measured separately. The collected samples for dry weight determination were deactivated for 0.5 h at 105 °C and dried for 72 h at 75 °C. Statistical data on the biomass of the root system and aboveground parts (stem and leaves) of single plantlets were obtained.

11.2.2.2 Measurement of $\delta^{15}N$ Content in Different Organs

Six *S. matsudana* seedlings were collected from each treatment after culture for 7, 14, 21, and 28 days to determine $\delta^{15}N$ content distribution in different organs. Fresh and dry weights were measured using the method presented in Sect. 11.2.2.1. The seedlings were dried, ground, and screened by a 100 mesh filter to determine $\delta^{15}N$ content. DELTA V Advantage isotope ratio mass spectrometer and Flash EA1112 HT elemental analyzer (Thermo Fisher Scientific, USA) were used to measure $\delta^{15}N$ content (error was controlled within $\pm <0.2‰$).

Atom%^{15}N (at.%), ^{15}N absorption, Ndff%, and ^{15}N distribution rate in different organs were analyzed using the calculation methods proposed by Lin (2013) and Zhao et al. (2006).

11.2.2.3 Analysis of Physiological Indexes

After culture for 28 d, several mature leaves at the third–fifth leaf positions and roots were collected in the morning from the residual complete seedlings, which exhibited acceptable appearance and uniform growth. The collected parts were immediately stored in a cooling box at 4 °C and transported to the laboratory to determine physiological indices. Each sample was tested three to six times. The physiological indices of leaf and root system were selected and analyzed using methods presented in previous studies. Catalase (CAT) activity was determined by ultraviolet absorption method; peroxidase (POD) activity was assessed through guaiacol oxidation; superoxide dismutase (SOD) activity was tested with NBT photoreduction; MDA (Malondialdehyde) level was determined by TBA method; and root system activity was tested through α-naphthalene oxidation (Zhang et al. 1990; Li 2000). And determination of CAT activity was conducted within 24 h, whereas the other indices were tested within 48 h. Root morphology was determined using a fully automatic double-light source root scanning analyzer and analyzed using the WinRHIZO Pro 2005b software (Regent Instruments). Length, area, volume, diameter, and tip amount of the roots were determined from the samples.

11.2.3 Data Treatment

Excel 2007 was applied for primary data analysis, and SPSS 18.0 was used for homogeneity test of variance. Biomass, ^{15}N, and physiological indices of leaves and roots, as well as root morphology, were subjected to single-factor (NH_4^+–N or NO_3^-–N) ANOVA (analysis of variance). LSD (least significant difference) was used for multiple comparative analysis ($p < 0.05$). Origin 7.5 was used in drawing figures.

11.3 Results and Analysis

11.3.1 Effect of Nitrogen Treatment on Biomass and Nitrogen Absorption

The effect of two N sources on the biomass differed between the root system and aboveground parts (Table 11.1). The biomass (dry weight) of the underground and aboveground parts of a single *S. matsudana* seedling significantly differed among different nitrogen treatments ($p < 0.05$). Results also demonstrated that increase in nitrogen concentration within a certain range could facilitate the growth of *S. matsudana*, but excessive nitrogen inhibited seedling growth. Moreover, NH_4^+–N inhibited growth more significantly than NO_3^-–N, which implied that *S. matsudana* preferred to absorb NH_4^+–N. Under the same nitrogen concentration, NH_4^+–N treatment presented higher at.%, ^{15}N absorption, and Ndff in different organs compared with NO_3^-–N treatment. The difference between the effects of both treatments intensified with increasing nitrogen concentration. The root exhibited the highest at.%, ^{15}N absorption, and Ndff, followed by the stem and leaf. According to the final nitrogen utility, the root system and leaf of *S. matsudana* reached the highest N absorption rate at high NO_3^-–N concentrations. Meanwhile, the nitrogen utility of the stem achieved the highest absorption rate at medium levels of NO_3^-–N. Excessive nitrogen concentration could not be completely assimilated and utilized by *S. matsudana*. This observation indicated that the two N sources exhibited varied effects on the growth and nitrogen absorption of *S. matsudana*. This difference was significant ($p < 0.05$) under high nitrogen concentrations (N3 and N4) and could be attributed to different absorption preferences of *S. matsudana* and transportation pathways of the two N sources.

11.3.2 Effect of Nitrogen Treatment on ^{15}N Absorption and Distribution

Generally, growing seedlings have increased N demand. The present experiment showed that at.% in the root and leaf significantly increased during culture of *S. matsudana* (Fig. 11.4). In particular, at.% significantly differed between NH_4^+–N and NO_3^-–N treatments ($p < 0.05$). at.% in the root and leaf increased continuously with increasing nitrogen concentration in the nutrient solution. In N1, at.% in

Table 11.1 Effect of nitrogen treatment on biomass, at.%, N%, ^{15}N absorption, and Ndff in different organs of *S. matsudana*

Organs	Nitrogen treatments	Biomass	AT (%)	N%	^{15}N absorption × 1000 (g)	Ndff (%)
	NH_4^+–N1	2.93 ± 0.27abA	3.10 ± 0.08dA	1.06 ± 0.11cB	0.97 ± 0.17cA	2.74 ± 0.08dA
	NH_4^+–N2	3.57 ± 0.51aA	5.58 ± 0.15cA	1.72 ± 0.09bA	3.43 ± 0.52cA	5.22 ± 0.15cA
	NH_4^+–N3	2.81 ± 0.37bB	10.50 ± 0.80bA	4.72 ± 0.32aA	14.00 ± 2.96aA	10.17 ± 0.80bA
Root	NH_4^+–N4	2.17 ± 0.09bB	18.96 ± 0.56aA	1.90 ± 0.10bB	7.88 ± 0.50bB	18.66 ± 0.56aA
	NO_3^-–N1	2.43 ± 0.31cA	3.04 ± 0.07dA	1.47 ± 0.10dA	1.09 ± 0.22cA	2.68 ± 0.06dA
	NO_3^-–N2	3.34 ± 0.24bA	3.92 ± 0.08cB	1.81 ± 0.20cA	2.37 ± 0.39cB	3.56 ± 0.08cB
	NO_3^-–N3	4.38 ± 0.27bA	7.51 ± 0.12bB	3.16 ± 0.12bB	10.42 ± 0.94bA	7.17 ± 0.12bB
	NO_3^-–N4	3.43 ± 0.24aA	13.85 ± 0.24aB	2.79 ± 0.17aA	13.30 ± 1.92aA	13.53 ± 0.24aB
	NH_4^+–N1	10.31 ± 1.00cA	1.25 ± 0.03cA	0.56 ± 0.12bB	0.72 ± 0.23bB	0.88 ± 0.03bA
	NH_4^+–N2	11.65 ± 1.11bcA	2.51 ± 0.04bcA	0.25 ± 0.10cB	0.75 ± 0.37bB	2.15 ± 0.04bA
	NH_4^+–N3	13.50 ± 0.84bB	5.09 ± 0.16bA	0.98 ± 0.14aB	6.77 ± 1.34bA	4.74 ± 0.16bA
Stem	NH_4^+–N4	16.76 ± 1.38aA	17.31 ± 2.81aA	0.72 ± 0.21abB	21.74 ± 10.96aA	17.00 ± 2.82aA
	NO_3^-–N1	11.67 ± 0.42dA	1.27 ± 0.03dA	1.45 ± 0.08bA	2.16 ± 0.14cA	0.91 ± 0.04dA
	NO_3^-–N2	13.09 ± 0.12cA	1.77 ± 0.04cB	3.25 ± 0.09aA	7.55 ± 0.44bA	1.41 ± 0.04cB
	NO_3^-–N3	22.22 ± 0.46aA	2.77 ± 0.10bB	1.13 ± 0.14cA	6.93 ± 0.68bA	2.41 ± 0.10bB
	NO_3^-–N4	14.40 ± 0.32bB	11.35 ± 0.32aB	1.15 ± 0.07cA	18.79 ± 1.25aA	11.02 ± 0.32aB
	NH_4^+–N1	3.85 ± 0.35bA	1.07 ± 0.01cA	2.02 ± 0.08cA	0.83 ± 0.12cA	0.70 ± 0.01cA
	NH_4^+–N2	4.25 ± 0.82bA	1.61 ± 0.05cA	1.61 ± 0.07 dB	1.10 ± 0.21cA	1.24 ± 0.05cA
	NH_4^+–N3	4.86 ± 0.85abB	2.75 ± 0.08bA	3.84 ± 0.17aB	5.11 ± 0.73bA	2.39 ± 0.08bA
Leaf	NH_4^+–N4	5.56 ± 0.47aA	10.58 ± 0.62aA	2.24 ± 0.05bB	13.22 ± 2.07aA	10.25 ± 0.62aA
	NO_3^-–N1	3.84 ± 0.51cA	0.62 ± 0.02dA	1.28 ± 0.09 dB	0.31 ± 0.06cB	0.25 ± 0.02 dB
	NO_3^-–N2	4.23 ± 0.31bcA	0.88 ± 0.05cB	2.41 ± 0.09cA	0.90 ± 0.10cA	0.51 ± 0.05cB
	NO_3^-–N3	7.45 ± 0.44aA	0.95 ± 0.04bB	4.52 ± 0.05aA	3.22 ± 0.28bB	0.59 ± 0.03bB
	NO_3^-–N4	4.85 ± 0.52bA	6.62 ± 0.03aB	3.40 ± 0.07bA	10.88 ± 1.00aA	6.27 ± 0.02aB

Note Different normal letters indicate significant difference ($p < 0.05$) between NH_4^+–N and NO_3^-–N treatments; and different capital letters indicate significant difference ($p < 0.05$) between NH_4^+–N and NO_3^-–N treatments under the same nitrogen concentration

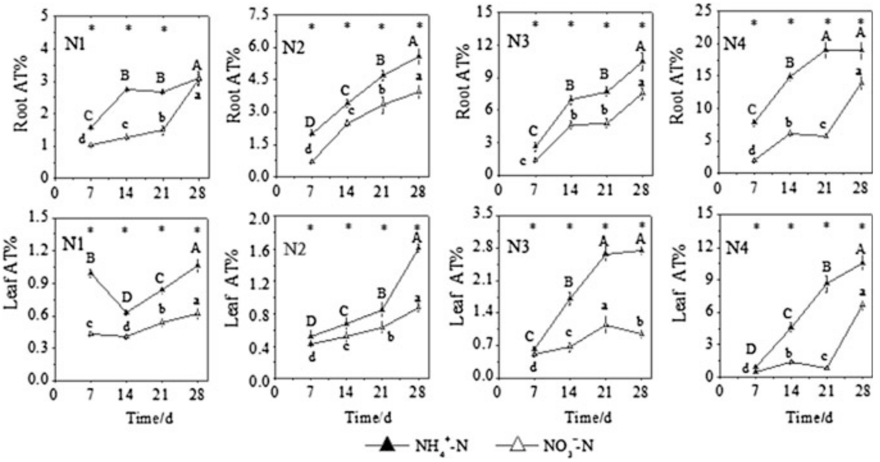


Fig. 11.4 Effects of nitrogen treatments on the absorption and distribution of nitrogen in *S. matsudana*. *Note* Different capital letters indicate significant difference ($p < 0.05$) among $NH_4{}^+$–N treatments; different normal letters indicate significant difference ($p < 0.05$) among $NO_3{}^-$–N treatments; *shows significant differences ($p < 0.05$) between $NH_4{}^+$–N and $NO_3{}^-$–N treatments

the root was not significantly different between $NH_4{}^+$–N and $NO_3{}^-$–N treatments, with values of 3.10 % and 3.04 %, respectively. Meanwhile, at.% in the leaf varied for $NH_4{}^+$–N treatment. After culture for 14 days, at.% (0.63 %) was lower than that for 7 days and was the lowest during the whole culture period. For N2, at.% significantly increased in the root and leaf with extended culture time. at.% in the root rapidly increased during the early period, whereas that in the leaf rapidly increased in late culture period. For N3, at.% in the root increased with increasing culturing time; however, at.% in the leaf under $NO_3{}^-$–N treatment started to decrease after 21 days of culture and then decreased to 17.4 % at 28 days. For N4, at.% in the leaf under $NH_4{}^+$–N treatment was saturated at 21 days. This result was more evident in the root. at.% in the root and leaf continuously increased within the first 14 days, decreased slightly from 14 to 21 days, and sharply increased thereafter. Furthermore, at.% in the root and leaf increased under the two treatments and reached the maximum at 28 days, with values of 18.96 % and 13.85 %, respectively, for $NH_4{}^+$–N treatment and 10.57 % and 6.62 %, respectively, for $NO_3{}^-$–N treatment.

For the four nitrogen concentrations, at.% in $NH_4{}^+$–N treatment was higher than that in $NO_3{}^-$–N treatment during the four sampling periods, which indicated that *S. matsudana* preferred to intake $NH_4{}^+$–N. at.% in the root and leaf significantly increased under N2 but decreased to different extents under N1, N3, and N4. Therefore, nitrogen cannot be continuously absorbed to different extents during the whole culture period; this finding may be due to different compatibilities of *S. matsudana* root system to the two N sources and the different effects of these sources on physiological characteristics of *S. matsudana* seedlings (Dong et al. 2009; Ariz et al. 2011b).

As a nutrient element, ^{15}N in plants accumulates with increasing culture time. However, under NO_3^-–N treatment, ^{15}N content slightly changed in the first 14 days, which demonstrated the presence of low ^{15}N absorption rate. By contrast, for NH_4^+–N treatment, ^{15}N absorption in the nutrient solution continuously increased with increasing culture time, but nitrogen absorption by the leaf reduced after 14 days of culture. This result may be due to nitration of some ^{15}N and other migrations, as well as the transformation effect (Huang et al. 2004).

The effects of two N sources on ^{15}N distribution in different organs of *S. matsudana* significantly differed with increasing nitrogen concentration ($p < 0.05$) (Table 11.2). For NH_4^+–N treatment, ^{15}N distribution rate in the root initially increased, subsequently decreased, and then peaked under N2. ^{15}N distribution rate in the leaf gradually decreased and reached the maximum under N1. For NO_3^-–N treatment, ^{15}N distribution rate in the root initially increased, subsequently decreased, and reached the peak value under N3. ^{15}N distribution rate in the leaf gradually increased and achieved the maximum value under N4.

11.3.3 Effects of Nitrogen Treatment on CAT, POD, SOD, and MDA in Leaf and Root

CAT activity in *S. matsudana* leaves presented a V- and S-shaped variation trends under NH_4^+–N and NO_3^-–N treatments, respectively, with increasing nitrogen concentration. The highest CAT activity in NH_4^+–N treatment occurred under N4, which was 232.02 % higher than that in the control group. The highest CAT activity in NO_3^-–N treatment was achieved under N3, which was 122.07 % higher than that in the control group. CAT activity in the root system under NH_4^+–N and NO_3^-–N treatments decreased and reached the peak under N4; the activity showed a V-shaped variation trend with increasing nitrogen concentration. The CAT activity values in the root system under NH_4^+–N and NO_3^-–N treatments were 155.75 and 638.87 % higher, respectively, than those in the control group (Fig. 11.5).

POD activity in the leaf under NH_4^+–N treatment initially decreased and then increased with increasing nitrogen concentration. By contrast, an opposite trend was observed under NO_3^-–N treatment. POD activity achieved the highest value under N4 (80.14 % higher than that in the control group) and presented the lowest data under N1 (39.52 % lower than that in the control group). POD activity in the root system under NH_4^+–N and NO_3^-–N treatments exhibited similar changes, that is, initially increased and then decreased. Moreover, POD activity in the root system with NH_4^+–N treatment showed the highest value under N4 and the lowest value under N1; these values were 47.03 % higher and 47.48 % lower than those in the control group, respectively). In contrast to that in NO_3^-–N treatment, POD

Table 11.2 Effect of nitrogen treatment on ^{15}N distribution rate in different organs of *S. matsudana*

Nitrogen type	Organs	Gradient of nitrogen			
		N1	N2	N3	N4
	Root	38.51 ± 5.63cA	64.79 ± 5.85aA	53.90 ± 3.49bA	19.14 ± 4.60 dB
NH_4^+–N	Stem	28.22 ± 4.59bB	14.53 ± 7.88bB	26.28 ± 3.43bA	48.93 ± 9.43aA
	Leaf	33.27 ± 4.29aA	20.67 ± 3.17bA	19.82 ± 0.78bA	31.93 ± 5.31aA
	Root	30.49 ± 2.86bA	21.87 ± 2.25cB	50.61 ± 2.27aA	30.87 ± 2.69bA
NO_3^-–N	Stem	60.95 ± 3.69bA	69.84 ± 2.68aA	33.74 ± 3.25dA	43.82 ± 3.64cA
	Leaf	8.56 ± 0.96cB	8.28 ± 0.72cB	15.66 ± 1.06bB	25.31 ± 1.02aA

Note see Table 11.1

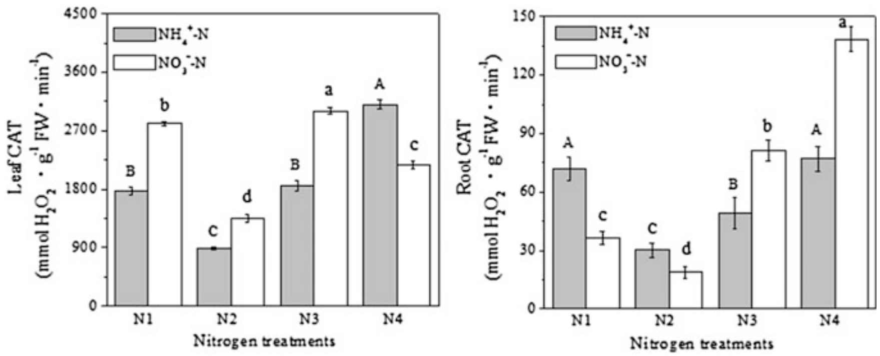


Fig. 11.5 Effect of nitrogen treatment on CAT activity in the leaf and root of *S. matsudana*. *Note* Different capital letters indicate significant difference ($p < 0.05$) among NH_4^+–N treatments, and different normal letters indicate significant difference ($p < 0.05$) among NO_3^-–N treatments

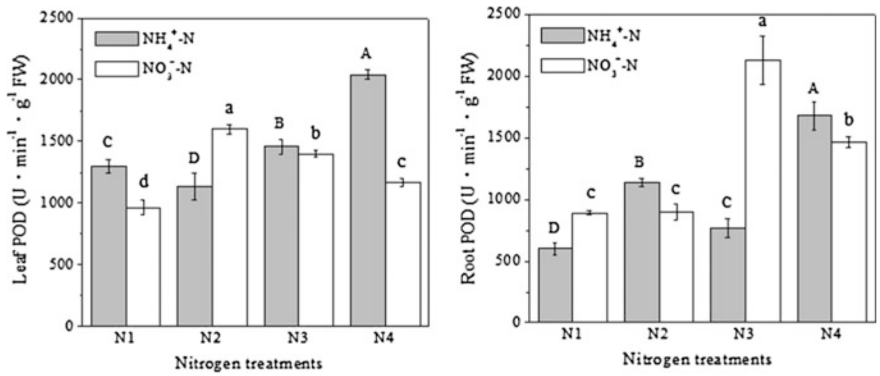


Fig. 11.6 Effect of nitrogen treatment on POD activity in the leaf and root of *S. matsudana*

activity reached the highest value under N4, which was 137.79 % higher than that in the control group (Fig. 11.6).

SOD activity in the leaf *S.* showed a V-shaped variation under NH_4^+–N treatment but continuously decreased under NO_3^-–N treatment with increasing nitrogen concentration. For NH_4^+–N treatment, the minimum SOD activity in the leaf was achieved under N4, which was 52.77 % lower than that in the control group. For NO_3^-–N treatment, the maximum and minimum SOD activities were obtained under N4 and N1, respectively; the maximum and minimum values were 24.48 % higher and 21.78 % lower than those in the control group, respectively. Furthermore, SOD activity in the root showed S- and V-shaped variation trends under NH_4^+–N and NO_3^-–N treatments, respectively. The maximum SOD activities in the root with NH_4^+–N and NO_3^-–N treatments were obtained under N1 (39.49 % higher than that in the control group) and N4 (53.89 % higher than that in the control group), respectively (Fig. 11.7).

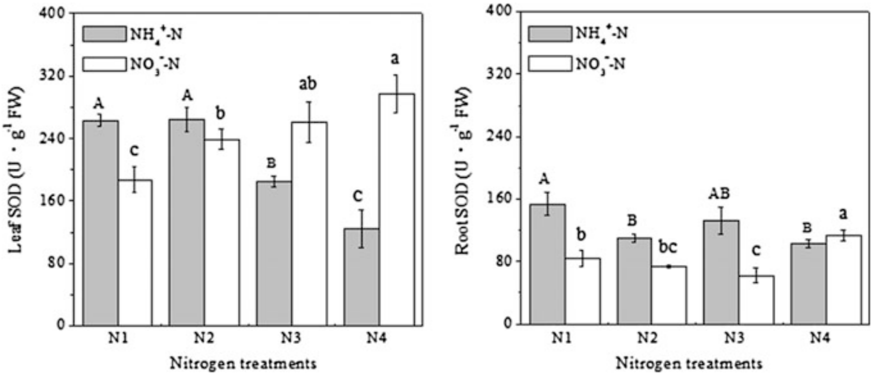


Fig. 11.7 Effect of nitrogen treatment on SOD activity in the leaf and root of *S. matsudana*

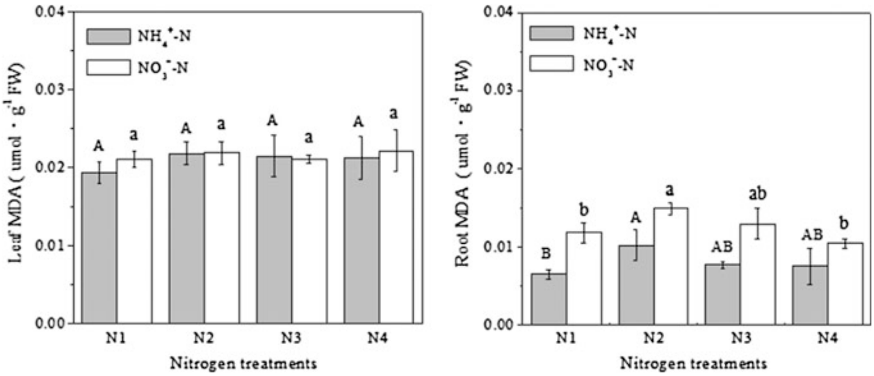


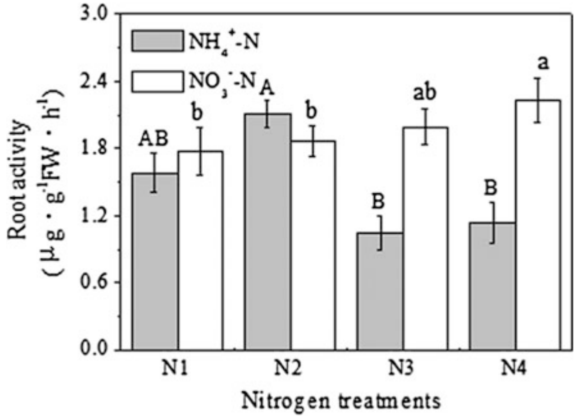
Fig. 11.8 Effect of nitrogen treatment on MDA contents in the leaf and root of *S. matsudana*

MDA content in leaves treated with NH_4^+–N and NO_3^-–N was not significantly different from that in the control group ($p < 0.05$) (Fig. 5). MDA content in the root system with NH_4^+–N and NO_3^-–N treatments initially increased and then decreased. The lowest MDA content was observed under N1 (36.16 % lower than that in the control group) for NH_4^+–N treatment and under N4 (29.85 % lower than that in the control group) for NO_3^-–N treatment (Fig. 11.8).

11.3.4 Effect of Nitrogen Treatment on Root Activity and Root Morphology

Root activity is an important parameter that indicates the physiological activities of plants. In this experiment, the physiological indices of *S. matsudana* exhibited significant differences with increasing nitrogen concentration in the nutrient

Fig. 11.9 Effect of nitrogen treatment on the root activity of *S. matsudana*



solution. Root activity under NH_4^+–N treatment initially increased and then declined. The lowest root activity was observed under N3 (50.61 % lower than that in the control group). By contrast, root activity under NO_3^-–N treatment continuously increased and then peaked under N4 (19.53 % higher than that in the control group) (Fig. 11.9).

Root morphological indices changed with increasing nitrogen concentration. The relative parameters of *S. matsudana* seedlings initially increased and then decreased (Table 11.3). The maximum average root diameter under NH_4^+–N treatment and amount of root tips under NO_3^-–N treatment were achieved under the control level (N2); this finding implied that inadequate or excessive NH_4^+–N and NO_3^-–N concentrations could inhibit the growth of *S. matsudana*. Under N1, root length, root surface area, average root diameter, root volume, and root tips were lower by 10.38, 8.02, 12.52, 19.66, and 17.73 %, respectively, in NH_4^+–N treatment than those in the control group; furthermore, these parameters were lower by 11.88, 31.05, 0.00, 21.04, and 36.20 % in NH_4^+–N treatment than those in the control group. Under N4, root length, root surface area, average root diameter, root volume, and root tips were lower by 30.92, 29.48, 19.44, 27.01, and 36.41 %, respectively, in NH_4^+–N treatment than those in the control group; these parameters were lower by 1.66, 5.65, 1.49, 5.06, and 25.72 %, respectively, in NO_3^-–N treatment than those in the control group.

Table 11.3 Root morphology dynamics of *S. matsudana* under different nitrogen treatments

Nitrogen species	Nitrogen treatments	Root length/1000	Root surface area (cm^2)	Average root diameter (mm)	Root volume (cm^3)	Root Tips/1000
NH_4^+–N	N1	8.03 ± 0.38cB	1675.08 ± 87.07bA	0.63 ± 0.02bcA	25.34 ± 7.99bA	16.56 ± 0.59cA
	N2	8.96 ± 0.69bB	1821.16 ± 60.80bB	0.72 ± 0.06aA	31.54 ± 4.70bA	20.13 ± 1.58bA
	N3	13.65 ± 0.26aA	2662.09 ± 173.84aA	0.65 ± 0.01bB	45.42 ± 1.80aA	32.10 ± 3.00aA
	N4	6.19 ± 0.43 dB	1284.34 ± 75.31cB	0.58 ± 0.03cB	23.02 ± 4.11bA	12.80 ± 0.71 dB
NO_3^-–N	N1	9.57 ± 0.39bA	1513.48 ± 101.23bA	0.67 ± 0.02bA	27.47 ± 4.64aA	17.41 ± 0.99bA
	N2	10.86 ± 0.79abA	2194.89 ± 162.08aA	0.67 ± 0.02bA	34.79 ± 7.62aA	27.29 ± 4.39aA
	N3	12.04 ± 0.40aB	2046.73 ± 166.42aB	0.71 ± 0.01aA	36.19 ± 7.97aA	20.18 ± 1.38bB
	N4	10.68 ± 1.00bA	2070.93 ± 192.90aA	0.66 ± 0.03bA	33.03 ± 7.91aA	20.27 ± 0.29bA

Note see Table 11.1

11.4 Discussion and Conclusions

This chapter concludes that inadequate or excessive NH_4^+–N and NO_3^-–N concentrations could inhibit the root growth of *S. matsudana*. Inadequate NO_3^-–N level inhibited the root growth more significantly than inadequate NH_4^+–N, but excessive NH_4^+–N inhibited the root growth more significantly than excessive NO_3^-–N compared with those in the control group. This result is consistent with those reported by Cruz et al. (2011) and Yan et al. (2013).

The effects of different N sources on *S. matsudana* can be possibly attributed to the following: (1) Plants often have high demands for carbohydrates because of the presence of antagonism and mutual promotion among ions, as well as high NH_4^+ concentration (Ariz et al. 2011a). (2) Changes in external environmental factors (e.g., temperature and light intensity) could alter the N distribution pattern in plants to a certain extent. (3) Different N sources exhibit varied effects on plant growth and physiological characteristics. Generally, high NH_4^+–N concentrations may cause toxicity to plants (Zhu et al. 2000). Moreover, plants have different sensitivities to different N sources. The pH of water also affects N absorption/distribution of plants, which could lead to different ^{15}N contents in plants (Ariz et al. 2011a). For NH_4^+ stress, substantial changes were observed among different plants or strains of the same plant. However, no consensus has been established yet. Changes in NH_4^+ can enhance or weaken complex physiological processes, but the underlying chemical mechanism remains unclear. In studying plant response to NH_4^+ stress, researchers believe that excessive NH_4^+ levels in the rhizosphere can increase the carbon consumption of plants. Therefore, NH_4^+ toxicity can be alleviated by increasing carbon source supply in the rhizosphere, as well as by changing osmosis and adding potassium ions (Ariz et al. 2011b).

CAT is widely distributed in animal and plant cells. As an active oxygen scavenger, CAT can decompose active oxygen species, such as H_2O_2 and O_2^-, which are produced during metabolic processes. These substances are toxic to plant bodies, specifically plasmalemma. Determination of CAT activity could be used to evaluate the toxicity of active oxygen on plants (Domínguez-Valdivia et al. 2008). In this chapter, CAT in the leaves of *S. matsudana* with low NH_4^+–N concentrations is less active than that with low NO_3^-–N levels; however, CAT in leaves of *Salix matsudana* with high NH_4^+–N concentrations is more active than that with high NO_3^-–N levels. CAT activity in the roots of *S. matsudana* presents an opposite trend to that in the leaves. CAT in the root with high NH_4^+–N concentration is less active than that with high NO_3^-–N levels. These results could be due to the fact that NH_4^+–N is more toxic to the leaves of *S. matsudana* under high concentrations but it is more toxic to the root systems under low concentrations. POD and SOD are important protective enzymes in plants. SOD mainly catalyzes the disproportionation of O_2^- into H_2O_2 and maintains low O_2^- concentrations in plant tissues, thereby eliminating the damage of O_2^- on cells. SOD activity is closely related to the oxidation resistance of plants. Meanwhile, POD could catalyze the decomposition of other substrates to consume H_2O_2. This enzyme

Fig. 11.10 Willows grow under different N levels (photograph taken by Jianfeng Zhang)

coordinates with SOD to effectively eliminate active oxygen species produced during metabolic processes, thus weakening membrane lipid peroxidation and other damages caused by active oxygen (Liu et al. 2011). These results could be attributed to harmful peroxides produced after NH_4^+ is introduced into the plants. The levels of peroxides in plants increase with increasing nitrogen concentration; thus, POD and SOD activities also increase. If excessive nitrogen levels exist, which could not be detoxicated by plants themselves, a toxic effect will be produced; this effect could lead to declined POD and SOD activities to a certain extent.

MDA is a common index of membrane lipid peroxidation. This enzyme is a product of membrane lipid peroxidation that occurs in aging plant organs or under adverse situations. MDA content represents cell membrane lipid peroxidation and plant tolerance to adverse environments. Determination of MDA content showed that inadequate and excessive nitrogen levels can inhibit the growth of *S. matsudana.* NH_4^+–N treatment is more inhibited compared with NO_3^-–N treatment. Root activity, which refers to the metabolism of the entire root system, directly influences physiological activity and biochemical processes of aboveground parts. Root is the organ where plants are in direct contact with NH_4^+; thus, roots can be easily poisoned by NH_4^+ (Fang et al. 2011). Therefore, the root activity of plants could accurately reflect NH_4^+ toxicity. This research demonstrates that NH_4^+–N affects the root activity of *S. matsudana* more significantly compared with NO_3^-–N, similar to the findings reported by Cruz et al. (Cruz et al. 2006).

Nitrogen generally accumulates in most vital parts of plants (Dong et al. 2009). Plants have different preferred N sources and can adjust the selective absorption of these sources when environmental conditions are changed (Wu et al. 2005; Nie et al. 2011. Inadequate and excessive nitrogen levels affect the growth and physiological activity of plants. Under NH_4^+–N alone, inadequate and excessive NH_4^+–N concentrations can impose certain toxicity to plant roots and leaves because different plant organs have different competitive absorptions toward different N sources.

To determine whether the ^{15}N absorption characteristics of *S. matsudana* are related to the anatomical structure or varietal specificity under two nitrogen treatments, scholars must perform further research on its absorption dynamics (see Fig. 11.10). When *S. matsudana* is used to remediate water pollution by nitrogen, a proportion of NO_3^-–N must be appropriately increased to enhance nitrogen absorption by *S. matsudana*.

References

Ariz I, Esteban R, García-Plazaola JI et al (2010) High irradiance induces photo protective mechanisms and a positive effect on NH_4^+ stress in *Pisum sativum* L. J Plant Physiol 167(13):1038–1045

Ariz I, Cruz C, Moran JF, González-Moro MB et al (2011a) Depletion of the heaviest stable N isotope is associated with NH_4^+/NH_3 toxicity in NH_4^+-fed plants. BMC Plant Biol 11(1):83

Ariz I, Artola E, Asensio AC et al (2011b) High irradiance increases NH_4^+tolerance in *Pisum sativum*: Higher carbon and energy availability improve ion balance but not N assimilation. J Plant Physiol 168(10):1009–1015

Chang HQ, Li N, Xu XF (2008) Research on NH_4^+ and NO_3^- uptake kinetics of three aquatic macrophytes. Ecol Environ 17(2):511–514

Chen CH, Liu ZK, Chen GC, San QH, Zhang JF (2011) Uptake kinetic characteristics of Cu^{2+} by *Salix jiangsuensis* CL J-172 and *Salix babylonica* Linn and the influence of organic acids. Acta Ecologica Sinica 31(18):5255–5263

Cheng LW, Zou DH, Zheng QS, Liu ZP, Li F, Jiang HP (2010) Effects of temperature and light intensity on the nitrate uptake kinetics of *Ulva lactuca* under nitrogen starved and replete. Chin J Ecol 29(5):939–944

Cruz C, Bio AFM, Dominguez-Valdivia MD et al (2006) How does glutamine synthetase activity determine plant tolerance to ammonium? Planta 223(5):1068–1080

Cruz C, Domínguez-Valdivia MD, Aparicio-Tejo PM et al (2011) Intra-specific variation in pea responses to ammonium nutrition leads to different degrees of tolerance. Environ Exp Bot 70(2):233–243

Domínguez-Valdivia MD, Aparicio-Tejo PM, Lamsfus C et al (2008) Nitrogen nutrition and antioxidant metabolism in ammonium-tolerant and sensitive plants. Physiol Plant 132(3): 359–369

Dong WY, Nie LS, Li JY et al (2009) Effects of nitrogen forms on the absorption and distribution of nitrogen in *Populus tomentosa* seedlings using the technique of 15 N tracing. Journal of Beijing Forestry University 31(4):97–101

Erisman JW, Sutton MA, Galloway J, Klimont Z, Winiwarter W (2008) How a century of ammonia synthesis changed the world. Nat Geosci 1:636–639

Fang YY, Yang XE, Chang HQ, Pu PM (2008) *In-situ* remediation of polluted water body by planting hydrophytes. Chin J Appl Ecol 19(2):407–412

Fang J, Chen GC, Lou C et al (2011) Effect of lead stress on root morphology and physical characteristic of willow (*Salix* spp.). J Anhui Agric Sci 39(15):8951–8953

Gao C, Zhu JG, Zhu JY, Gao X et al (2004) Nitrogen export from an agriculture watershed in the Taihu Lake area, China. Environ Geochem Health 26(2):199–207

Huang JG (2004) Plant nutrition. China Forestry Publishing House, Beijing, pp 82–106

Huang JL, Zou YB, Peng SB et al (2004) Nitrogen uptake, distribution and loss in tissues of rice. Plant Nutr Fertilizer Sci 10(6):579–583

Kuang YW, Sun FF, Wen DZ et al (2011) Nitrogen deposition influences nitrogen isotope composition in soil and needles of *Pinus massoniana* forests along an urban-rural gradient in the Pearl River Delta of south China. J Soils Sediments 11(4):589–595

Li HS (2000) Principle and technology of plant physiological and biochemical experiments. China Higher Education Press, Beijing, pp 134–260

Lin GH (2010) Stable isotope ecology: a new branch of ecology resulted from technology advances. Chin J Plant Ecol 34(2):119–122

Lin GH (2013) Stable isotope ecology. Higher Education Press, Beijing, pp 1–16

Liu ZK, Chen CH, Chen GC et al (2011) Growth and physiological characteristics of *Salix jiangsuensis* and *Salix babylonica* seedling under Cu^{2+} stress. Acta Botanica Boreali-Occidentalia Sinica 31(6):1195–1202

Liu XJ, Zhang Y, Han WX, Tang A, Shen JL et al (2013) Enhanced nitrogen deposition over China. Nature 94:459–462

Nie M, Lu M, Yang Q, Zhang XD et al (2011) Plants' use of different nitrogen forms in response to crude oil contamination. Environ Pollut 159(1):157–163

Wang MC, Liu XQ, Zhang JH (2002) Evaluate method and classification standard on lake eutrophication. Environ Monit China 18(5):47–49

Wang QL, Wu LS, Zhao ZQ (2007) Advance and application of ^{15}N tracer method on research of plant nitrogen nutrition. J Huazhong Agric Univ 26(1):127–132

Wang XY, He MR, Liu YH et al (2008) Effect of water-nitrogen interaction on nitrogen fertilizer absorption and nitrate-N movement across soil profile in a winter wheat field. Acta Ecologica Sinica 28(2):685–694

Wang Y, Zhang JF, Chen GC (2012) Removal efficiency and uptake kinetics of nitrogen in water body by *Salix integra*. Chin J Ecol 31(9):2305–2311

Wang QB, Zhang JF, Chen GC (2013) Review of nitrogen cycle in plant-soil system based on ^{15}N. J Trop Subtrop Bot 21(5):479–488

Wu C, Wang ZQ, Fan ZQ (2005) Relationships between nutrient utility and growth, and between nutrient partitioning patterns and biomass partitioning patterns in *Fraxinus mandshurica* seedlings supplied with different ratios of nitrogen forms. Acta Ecologica Sinica 25(6): 1282–1290

Yan H, Wu Q, Ding J, Zhang SR (2013) Effects of precipitation and nitrogen addition on photosynthetically eco-physiological characteristics and biomass of four tree seedlings in Gutian Mountain, Zhejiang Province. China. Acta Ecologica Sinica 33(14):4226–4236

Zhang ZL, Qu WQ, Li XF (1990) Plant physiology experiment instruction. China Higher Education Press, Beijing, pp 36–38

Zhang QF, Zheng SJ, Xia L (2010) Concepts and characteristics of phytoremediation. Garden 1:62–64

Zhao DC, Jiang YM, Peng FT, et al (2006) Effect of timing of ^{15}N supply on storage and remobilization of nitrogen by Chinese jujube (*Zizyphus jujuba* Mill. var. *inermis* Rehd) seedling. Scientia Agricultura Sinica 39(8):1626–1631

Zhu Z, Gerendas J, Bendixen R et al (2000) Different tolerance to light stress in NO_3^- and NH_4^+grown *Phaseolus vulgaris* L. Plant Biol 2(5):558–570

Chapter 12
Influences of Protective Forest Construction on Soil Nutrient Dynamics

Abstract This study aimed to determine the effect of establishing protective forests on soil nutrient dynamics in the Taihu Lake area. The experiment was performed in Yixing City to determine changes in soil organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus, and available potassium. Results showed the evident effects of building protective forests along the lake on changes in soil nutrient content, which exhibited a constant trend. Establishment of protective forests could effectively reduce soil nutrient content compared with that in farmland soil. In forested lands, soil organic matter and available potassium content decreased by 29.06 and 26.33 %, respectively, whereas total nitrogen, total phosphorus, and available phosphorus decreased by more than 30 %. Hence, this research implied that building protective forests could achieve source reduction effect and increased sink for non-point source pollution. From October 2009 to May 2011, the ecological restoration area with reduced loads of pure nitrogen and phosphorus reached 46.3–69.54 and 3.78–7.3 g/m^2, respectively, through source reduction and increased sink.

Keywords Taihu Lake · Protective forest · Soil nutrient · Source reduction · Sink increasing · Forested land · Ecological effect · Soil organic matter · Total nitrogen · Total phosphorus · Available phosphorus · Total potassium · Available potassium

Taihu Lake, one of the five largest freshwater lakes in China, has an area of 2427.8 km^2 and an actual water surface area of 2338 km^2 (Xue et al. 2008; Yu et al. 2011; Jia et al. 2007). Recently, water resource in the Taihu Lake watershed has been seriously polluted because of rapid socioeconomic development. The degree of eutrophication gradually aggravates because of continued input of high concentrations of pollutants from rivers and channels, thereby leading to deteriorating water quality (Chen and Li 2014; Cheng et al. 2005). Agricultural non-point source pollution is an important factor that directly causes eutrophication in Taihu Lake. Numerous studies showed that agricultural non-point source pollution accounts for 34–52 % of total nitrogen and 17–54 % of total phosphorus (Li et al. 2007;

J. Zhang, *Forestry Measures for Ecologically Controlling Non-point Source Pollution in Taihu Lake Watershed, China*, DOI 10.1007/978-981-10-1850-3_12

Reidsma et al. 2012; Yan et al. 2010). Hence, controlling agricultural non-point source pollution is a key strategy to improve the ecological environment of the Taihu Lake watershed.

12.1 Introduction

About 40 million residents of the Changjiang River Delta region obtain their drinking water from Taihu Lake. In 2007, blue-green algae outbreak occurred in Taihu Lake because of different factors; this outbreak results in a drinking water crisis and has attracted serious concerns from all levels of the government. Afterward, water pollution control in Taihu Lake has gradually received significant attention, and several assignments have been initiated and unfolded (Xu et al. 2013). Construction of protective forests (shelter forests) or public welfare forests around the Taihu Lake shore zone began in 2007. The total area of the established protective forests in the Yixing region reached 60,000 hm^2 in 2010 (Zhang et al. 2010) (see Figs. 12.1, 12.2, and 12.3). As water conservation is the main priority for the protective forests in the Taihu Lake watershed, intercepting TN and TP with surface runoff is performed to significantly prevent agricultural non-point source

Fig. 12.1 Protective forests are established along the channel in Yixing (photograph taken by Jianfeng Zhang)

Fig. 12.2 Shelter belts are established along riverbanks in Yixing (photograph taken by Jianfeng Zhang)

pollution (Xue et al. 2008). Generally, nitrogen and phosphorus are nutrients for plant growth (Feng et al. 2010). However, water eutrophication occurs when these elements enter into water through soil erosion; this phenomenon indicates water contamination, although this pollution seems not so vital for human life. Research shows that planting forests not only reduce loss of soil nutrients but also improve soil conditions; moreover, planting forests play a role in source reduction and sink increase, thereby effectively protecting the quality of surface water and groundwater (Wu et al. 2011; Zhang et al. 2009). Previous studies on protective forests focused on the importance of conserving soil and water and preventing soil erosion, but few studies investigated the control of agricultural non-point source pollution. The present study mainly focused on the effect of protective forests on dynamic changes in soil nutrients in the Yixing section of Taihu Lake. This research provides theoretical basis for constructing protective forests in the Taihu Lake watershed and promoting control of non-point source pollution in the future.

Fig. 12.3 Public welfare forests are established in Yixing (photograph taken by Jianfeng Zhang)

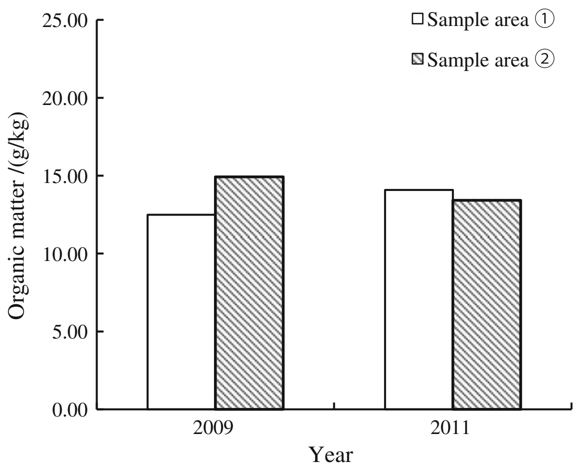


Fig. 12.4 Changes in organic matter content in sample areas ① and ②

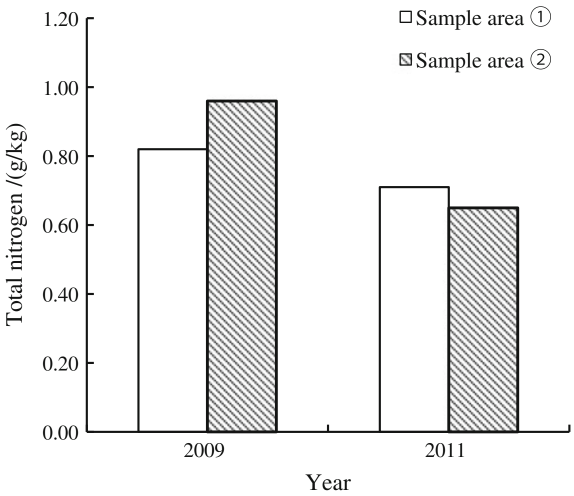


Fig. 12.5 Changes in total nitrogen content in sample areas ① and ②

12.2 Materials and Methods

12.2.1 Study Area

The Taihu Lake watershed is located in the southern part of Changjiang River Delta, across Jiangsu and Zhejiang provinces and Shanghai City; the total length of the Taihu Lake basin is about 120,000 km (Wo et al. 2007; Zhang and Liu 2011). This study was conducted in Yixing (latitude, 31°07′–31°37′N; longitude, 119°31′–120°03′E), which is located in the west bank of Taihu Lake and has a water area of 242.29 km^2. The shore length of Taihu Lake in Yixing is 43.5 km. The lake is connected to 14 provincial-controlled and state-managed rivers and channels, which include Shaoxiang, Dapu, Baidu, and 12 municipal-controlled channels; the lake is also linked to a total of 26 rivers and channels (Wang et al. 2012). In this research, Baidu and Shaoxiang channels, which are two major channels connected to the lake, were selected as test sites for studies on soil nutrients.

12.2.2 Methods

12.2.2.1 Soil Sample Collection

In October 2009 and May 2011, soil samples were collected in the study area by using the following sampling design. The main channel into the Lake Baidu and Shaoxiang channels were used for two repetitions, with every repetition having three standard selections for sampling: (1) riverbank slope stand of the protective forest (sampling scope = about 1 km long and 5 m wide); (2) platform stand of the protective forest near the lake (sampling scope = about 1 km long and 50 m wide); and (3) near the farmland stand of the protective forest (sampling scope = about 1 km long and 500 m wide). For each sampling site, three soil profiles were obtained. Samples were collected according to the following principles: randomized, equal amounts, and multipoint (10 points). Each subsample was obtained from the surface (0–20 cm) to the deep layer (20–40 and 40–60 cm).

12.2.2.2 Plant Sample Collection and Analysis

In May 2011, samples of the main afforestation tree species were collected in the same site by using a similar sampling design. Three replicates were performed for each tree species (not at the same place). Six trees of the species were randomly selected for every repetition. Trees with lengths of more than 1.3 m and 2-year-old branches were collected as samples, and the leaves were removed. The branches were placed in a cooling box and transported to the laboratory. Indoor plant samples were first rinsed with tap water and then with deionized water three times. The samples were air-dried and placed in an oven at 105 °C for 30 min. Afterward, the temperature of the oven was set at 75 °C until a constant weight was obtained. The dried samples were mechanically ground for chemical analysis. The powder was sealed into plastic bags and then stored.

The carbon content of the plant samples was determined through potassium dichromate oxidation with external heating. Nitrogen concentration was measured by the Kjeldahl method with nitric acid and perchloric acid digestion. Phosphorus level was analyzed using Mo–Sb colorimetry with nitric acid and perchloric acid digestion. Potassium content was determined through flame photometry method with nitric acid and perchloric acid digestion.

12.2.2.3 Investigation of Agricultural Production in Test Plots

In the study area, natural villages were considered a unit, and the agricultural production approach was used. Table 12.1 shows the questionnaire regarding the design and indicators for soil nutrient input and input analysis in the region.

12.3 Results and Analysis

12.3.1 Effect of Different Terrains on Soil Nutrient Contents

Sample areas ① and ② belong to the main channels in Taihu Lake; on both banks, the protective forests were established within the range of 50 m offshore to prevent surface runoff. In the area, land formation was conducted according to the need for

Table 12.1 Questionnaire on agricultural production in test plots

Village name	Land type	Crops	Plant area	Crop rotation	Quantity of nitrogen fertilizer (g/m^2 a) (pure nitrogen)	Quantity of phosphorus fertilizer (g/m^2 a) (P_2O_5)
	Non-irrigation land					
	Paddy field					
	Forested land					

Fig. 12.6 Changes in total phosphorus content in sample areas ① and ②

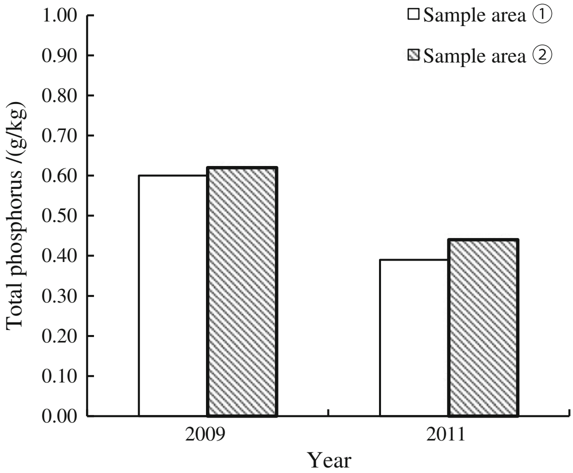
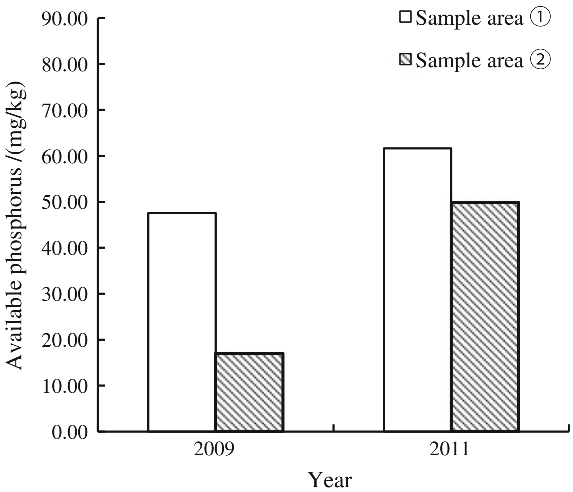


Fig. 12.7 Changes in available phosphorus content in sample areas ① and ②



ecological improvement and the characteristics of the original topography and distance to the river. A new terrain landscape was formed to reduce soil and water erosion. The results showed that soil total phosphorus and potassium contents in sample area ② were higher than those in sample area ①, and the result was consistent (Figs. 12.6 and 12.8). For the second sampling, the results of organic matter, total nitrogen, and available potassium contents were consistent, and the difference varied between sample sites ② and ① (Figs. 12.4 and 12.5). The available phosphorus content was significantly higher in sample area ① than that in sample area ② (*t* test, $P < 0.05$) (Fig. 12.7). Accordingly, the effect of different terrain treatments on changes in soil nutrient contents was not significant and failed to form a regular trend; nevertheless, the underlying mechanism must be further investigated (Figs. 12.9, 12.10, 12.11, and 12.12).

Fig. 12.8 Changes in total potassium content in sample areas ① and ②

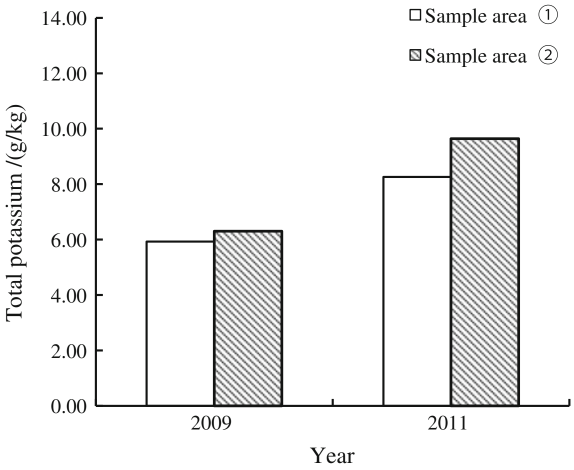
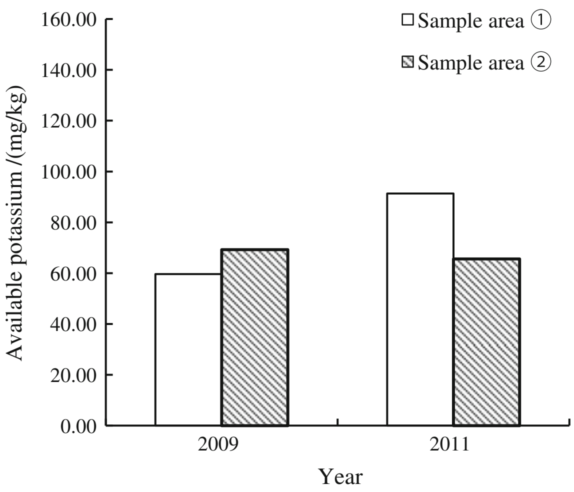


Fig. 12.9 Changes in available potassium content in sample areas ① and ②. *Note* Sample area ① is the riverbank slope stand of the protective forest, and sample area ② is the platform stand of the protective forest near the lake



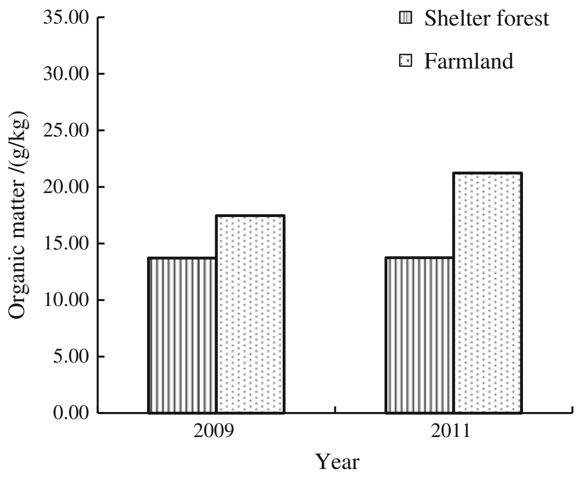


Fig. 12.10 Changes in organic matter content in shelter forest and farmland soil

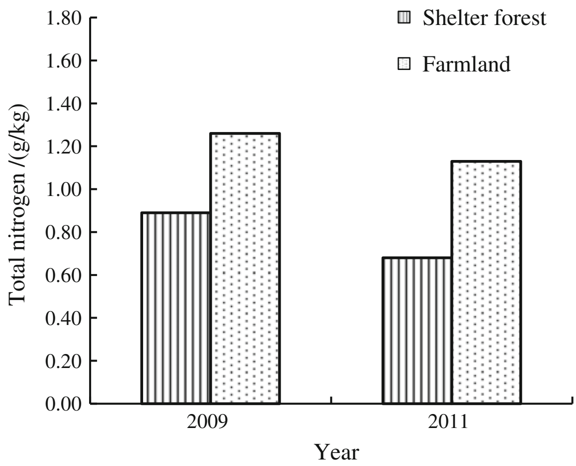


Fig. 12.11 Changes in total nitrogen content in shelter forest and farmland soil

12.3.2 Influence of Different Land Use Ways on Soil Nutrient Content

The shelter forests of the Taihu Lake shore zone were mainly constructed to reduce excessive soil nutrients and maintain the dynamic balance of nutrients between soils and plants. This research showed that soil organic matter, total nitrogen, total phosphorus, and available phosphorus contents were significantly higher in farmlands than in shelter forests (t test, $P < 0.05$) (Fig. 12.13). The total potassium content was not significantly different between farmlands and shelter forests but presented a higher tendency in the latter (Fig. 12.14). Meanwhile, the available potassium content was not significantly different among different land use ways.

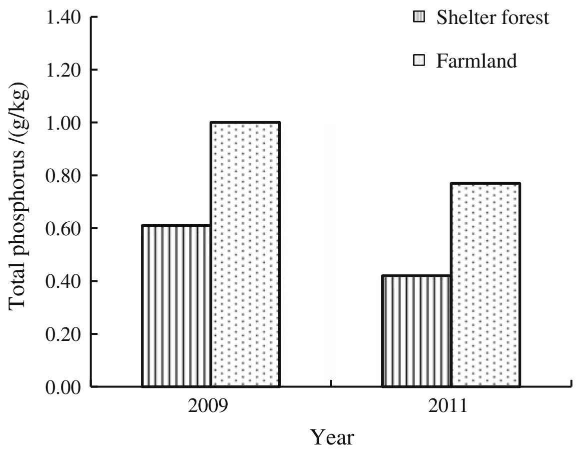


Fig. 12.12 Changes in total phosphorus content in shelter forest and farmland soil

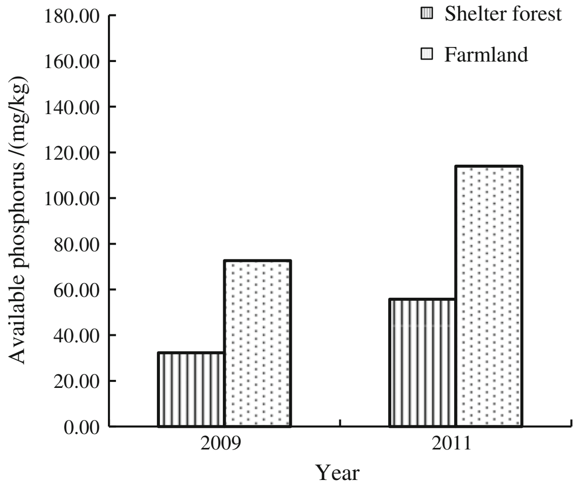


Fig. 12.13 Changes in available phosphorus content in shelter forest and farmland soil

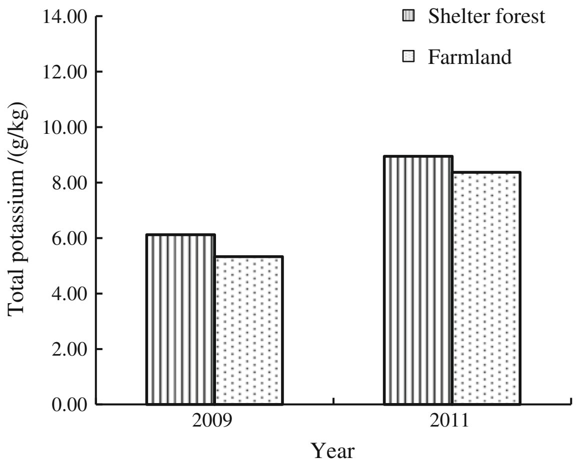


Fig. 12.14 Changes in total potassium content in shelter forest and farmland soil

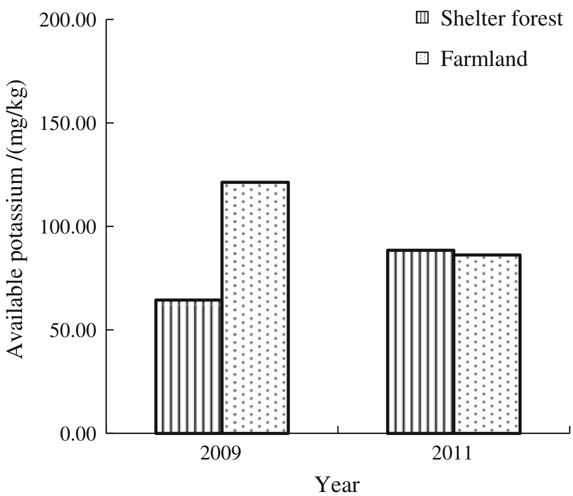


Fig. 12.15 Changes in available potassium content in shelter forest and farmland soil

Generally, the average changes in nutrient contents were higher in farmlands than in shelter forests (Fig. 12.15).

Shelter forests were mainly built to reduce pollution source. For this section, quantitative analysis was conducted on soil nutrient reduction in shelter forests by using comprehensive data collected in 2009 and 2011 (in average) and data from the stand of the shelter forests adjacent to the farmlands as control. Table 12.2 shows that soil organic matter and available potassium contents decreased as the trees grow, and the reduction rates reached 29.06 and 26.33 %, respectively (nearly 30 %). The effect was more significant for total and available phosphorus contents, with reduction rates of more than 30 %. A similar effect was observed for total and available potassium contents, which decreased in forested lands (Table 12.2).

Table 12.2 Analysis of nutrient index difference in shelter forest and farmland

Nutrient index	Shelter forest	Farmland	Difference value	Difference rate (%)
Organic matter (g/kg)	13.73	19.35	5.62	29.06
Total nitrogen (g/kg)	0.78	1.20	0.41	34.47
Total phosphorus (g/kg)	0.51	0.88	0.37	41.92
Available phosphorus (mg/kg)	44.02	93.30	49.28	52.82
Total potassium (g/kg)	6.85	7.53	0.68	9.03
Available potassium (mg/kg)	76.45	103.78	27.33	26.33

Note The nutrient index is the average of 2009 and 2011 data; difference value = farmland nutrient index − shelter forest nutrient index; difference rate (%) = (farmland nutrient index − shelter forest nutrient index)/farmland nutrient index × 100

12.3.3 Soil Nutrient Load Change

Soil nutrient load is an important parameter for controlling agricultural non-point source pollution. Protective forests decrease soil nutrient input (acting as source reduction, no demand on artificial fertilization) and increase soil nutrient output (acting as sink expansion, trees growing to absorb nutrients from soils). Therefore, soil nutrient contents decreased through source reduction by completely eliminating chemical fertilizer input in ecological protection area along Taihu Lake and connected rivers. Sink increase apparently occurred by transferring farmlands to woodlands, which depends on growing trees that consume soil nutrients. Moreover, a large amount of biomass was accumulated as timbers and other forest products with forest growth, indicating its multiple functions annually.

In this test, source reduction was analyzed by surveying 31 natural villages, including Dingxi, Shuangqiao, and Xiwang villages. The basic situation of agricultural production in the villages, i.e., arable land type, cash crops, acreage, crop rotation, nitrogen, and phosphate fertilizer application, and other relative records were obtained; the results are summarized in Table 12.3.

As shown in Table 12.3, the established shelter forests, which could effectively reduce the nitrogen and phosphorus inputs in the study area, reduced the nitrogen and P_2O_5 inputs by 41.23–64.47 and 7.08–15.14 g/m^2, respectively. In this region, the area of shelter forests was 16 km^2; thus, the total annual reductions of nitrogen and P_2O_5 inputs were 6.6×10^5–1.03×10^6 and 1.13×10^5–2.42×10^5 kg, respectively.

Growing trees absorbed nutrients from soils and then formed biomass, and this phenomenon is regarded as the main pathway of sink expansion. The degree of sink expansion was evaluated by analyzing element content of trees. In the measurement, nutrient element contents from the main afforestation tree species in the study

Table 12.3 Basic agricultural production summary for 31 villages

Villages	Land type	Crops	Area (km^2)	Crop rotation	Quantity of nitrogen fertilizer (g/m^2 a) (pure nitrogen)	Quantity of phosphorus fertilizer (g/m^2 a) (P_2O_5)
Summation	Non-irrigation land	Vegetable	14.34	Three times growing for one year	64.47	15.14
	Paddy field	Rice, wheat (rape)	31.65	Paddy upland rotation	41.23	7.08
	Forested land	Economic forest, shelter forest	40.73	–	–	–

Table 12.4 Nutrient element content analysis for main afforestation tree species

Tree species	C (g/kg)	N (g/kg)	P (g/kg)	K (g/kg)
Ligustrum lucidum	515.33 ± 39.36	4.11 ± 0.05	0.60 ± 0.2	3.17 ± 0.2
Cinnamomum camphora	537.33 ± 33.07	3.44 ± 0.88	0.40 ± 0.24	2.05 ± 1.41
Salix matsudana Koidz	565.33 ± 61.82	4.11 ± 0.05	0.60 ± 0.2	3.17 ± 0.2
Populus sp.	517 ± 12.03	3.44 ± 0.88	0.40 ± 0.24	2.05 ± 1.41
Koelreuteria paniculata	485.33 ± 56.05	5.83 ± 0.11	0.54 ± 0.02	3.25 ± 0.02
Bischofia polycarpa	565.67 ± 22.87	3.22 ± 0.12	0.32 ± 0.01	3.48 ± 0.28
Cedrus deodara	535.33 ± 44.19	4.88 ± 1.38	0.87 ± 0.17	3.28 ± 1.94
Metasequoia glyptostroboides	596.33 ± 4.19	3.45 ± 0.40	0.63 ± 0.06	3.30 ± 0.18

area were analyzed to determine sink increase, and the results are presented in Table 12.4.

Generally, the ratio of forest aboveground biomass and the stand height were constant at 1.06 kg/m^2/m and 1.06 kg/m^3 (biomass in dry matter), respectively. In the test area, the main afforestation tree species included *Salix matsudana* Koidz, *Cinnamomum camphora*, *Ligustrum lucidum*, *Koelreuteria paniculata*, *Populus* sp., *Bischofia polycarpa*, *Cedrus deodara*, and *Metasequoia glyptostroboides*. The stand average heights were 4.26 ± 1.03 m in 2009 and 5.44 ± 1.25 m in 2011. The aboveground biomasses of lake shore shelter forest were approximately 4.52 kg/m^2 in 2009 and 5.77 kg/m^2 in 2011 (i). As shown in Table 12.4, for the main afforestation tree species, the average contents of C, N, P, and K (ii) were 539.71 ± 35.11, 4.06 ± 0.90, 0.55 ± 0.17, and 2.97 ± 0.57 g/kg, respectively. Subsequently, we could use (i) × (ii) to estimate the fixed amounts of C, N, P, and K per square meter in the aboveground part of shelter forests. The fixed C, N, P, and K contents aboveground of the shelter forest were 2439.48, 18.34, 2.48, and 13.42 g/m^2, respectively, in October 2009 and 3114.12, 23.42, 3.16, and 17.13 g/m^2, respectively, in May 2011. Therefore, from October 2009 to May 2011, the fixed nutrient amounts for ΔC, ΔN, ΔP, and ΔK were 674.64, 5.07, 0.69, and 3.71 g/m^2, respectively. The function of forests on sink increase is important to combat non-point source pollution.

12.4 Discussion and Conclusions

In this study, main rivers linked with Taihu Lake, such as Baidu and Shaoxiang channels, were used as test sites. The ecological benefits of the protective forest along the lake shore (could be considered vegetation buffer zone) were assessed (see Fig. 12.16). Excessive nutrients entering into water are mainly caused by soil and water erosion; hence, water and soil particles are the carrier of the solution and the solid state of nutrients, respectively. During raining and surface runoff, nutrients transfer and migrate in the form of runoff entering into water. As such, vegetation buffer zones in riparian areas must be constructed. The buffer zone mainly functions

Fig. 12.16 Trees are planted as buffer zone of Taihu Lake (photograph taken by Jianfeng Zhang)

by reducing the environmental nutrient input of soil–water system, increasing the output of nutrients from the system, and consequently decreasing nutrient contents effectively. Moreover, the zone increases the diversity of species and surface vegetation coverage, alleviates rainwash to soils, improves soil structure, enhances rainwater infiltration, conserves water, and reduces surface runoff and soil erosion.

The following conclusions were obtained through the in situ test performed in this study. (1) The influence of different terrain changes on soil nutrient content was not significant; hence, despite the kind of terrain, soil nutrition levels are high in this region. (2) Shelter forests could effectively reduce the contents of nutrient elements in soils. In the shelter forest soil, organic matter and available potassium contents decreased by 29.06 and 26.33 %, respectively, and total nitrogen, total phosphorus, and available phosphorus decreased by more than 30 % compared with those in farmland soils. (3) Shelter forests reduced soil nutrient load through source reduction and sink increase. Based on the field survey and calculation, the shelter forests in the test shore zone could annually reduce pure nitrogen and P_2O_5 inputs by 41.23–64.47 and 7.08–15.14 g/m^2, respectively (source reduction). From October 2009 to May 2011, the newly fixed nutrient amounts of ΔC, ΔN, ΔP, and ΔK were 674.64, 5.07, 0.69, and 3.71 g/m^2, respectively (sink increase), in the shelter forests. Considering source reduction and sink increase, pure nitrogen and phosphorus load reductions in the test area were 46.3–69.54 and 3.78–7.3 g/m^2, respectively, from October 2009 to May 2011.

This study shows that shelter forests play a positive role in reducing soil nutrients. In the studied region, excessive fertilizers were applied in farmlands because of intensive management, and water eutrophication could be due to the occurrence of soil and water erosion. Hence, developing protective forests and decreasing soil nutrients are necessary to protect water quality from pollution sources.

References

Chen XH, Li XP (2014) Using quantile regression to analyze the stressor-response relationships between nutrient levels and algal biomass in three shallow lakes of the Lake Taihu Basin, China. Chin Sci Bull 59(28):3621–3629

Cheng B, Zhang Z, Chen L et al (2005) Eutrophication of Taihu Lake and pollution from agricultural non-point sources in Lake Taihu Basin. J Agro Environ Sci 24(Supplement):118–124

Feng LJ, Li F, Sun DZ et al (2010) Study on removing nonpoint source pollutants-nitrogen and phosphorus by vegetation of protection forest system. J Harb Univ Commer (Nat Sci Ed) 5:548–550

Jia D, Chen JL, Wang SH et al (2007) Farm ecosystem management and control of non-point source pollution in Taihu Lake area, China. Resour Environ Yangtze Basin 16(4):489–493

Li HP, Yang GS, Huang WY et al (2007) Simulating fluxes of non-point source nitrigen from upriver region of Taihu Basin. Acta Pedol Sin 44(6):1063–1069

Reidsma P, Shuyi F, Loon MV et al (2012) Integrated assessment of agricultural land use policies on nutrient pollution and sustainable development in Taihu Basin, China. Environ Sci Policy 18:66–76

Wang Y, Zhang JF, Chen GC et al (2012) Responses of water quality to landscape pattern in Taihu watershed: case study of 3 typical streams in Yixing. Acta Ecol Sin 32(20):6422–6430

Wo F, Chen XM, Wu HS et al (2007) Pollution situation of nitrogen and phosphorus in rural water environment in typical region of Taihu Lake. J Agro Environ Sci 26(3):819–825

Wu DM, Xue JH, Wu YB (2011) Reviews on effects of ecological shelterbelts on alleviating non-point source pollution of nitrogen. J Nanjing Forest Univ (Nat Sci Ed) 35(6):134–138

Xu S, Huang B, Zhong BW et al (2013) Seasonal variation of phytoplankton nutrient limitation in Lake Taihu, China: a monthly study from Year 2011 to 2012. Ecotoxicol Environ Saf 94:190–196

Xue JH, Ruan HH, Liu JG et al (2008) The construction techniques and strategies of riparian shelterbelt systems surrounding Taihu Lake watershed. J Naijing Forest Univ (Nat Sci Ed) 32(5):13–18

Yan LZ, Shi MJWL (2010) Review of agricultural non-point pollution in Taihu Lake and Taihu Basin. China Population Resour Environ 20(1):99–107

Yu H, Zhang LL, Yan SW et al (2011) Atmospheric wet deposition characteristics of nitrogen and phosphorus nutrients in Taihu Lake and contributions to the lake. Res Environ Sci 24(11):1210–1219

Zhang LC, Liu CL (2011) Characteristics of land use and its mechanism in Taihu Lake Basin. Resour Environ Yangtze Basin 20(10):1205–1210

Zhang JF, Jiang JM, Zhang ZJ et al (2009) Discussion on role of forest to control agricultural non-point source pollution in Taihu Lake Basin-based on source-sink analysis. Water Resour Prot 1:345–350

Zhang JF, Sheng HQ, Gu CL et al (2010) Discussion on the construction of ecological public welfare forests in Taihu Lake Basin at Yixing. J Anhui Agri Sci 38(18):9720–9749

Chapter 13
Ecological Effects of Tree Planting on Taihu Lake Watershed

Abstract Ecological protective forests are important to maintain regional ecological security. Construction of protective forests in Taihu Lake started in 2007 in Yixing, and new forested areas expanded to 56.67 km^2 by the end of 2010. In this study, protective forests and farmlands in Yixing were selected as test plots. Plant diversity and surface runoff characteristics were determined by surveying and collecting soil samples. Results showed that construction of ecological protective forests improved soil permeability, reduced surface runoff, and enhanced plant species diversity. Therefore, construction of ecological protective forests could be an effective measure for improving regional environmental security, enhancing soil status, and increasing plant biodiversity. Development of ecological protective forests is an important strategy to improve the environment within the Taihu Lake basin.

Keywords Taihu lake · Surface runoff · Plant diversity · Protective forest · Ecological effect · Tree planting · Soil conditions · Soil permeability · Farmland · New forested area · Ecological security

Taihu Lake, one of five largest freshwater lakes in China (Zhang and Wang 2007), is located in the southern part of Yangtze River Delta, which is an important economic center and one of the most developed regions in the country in terms of social and economic development (Ji et al. 2006). In recent years, the economy in the Taihu Lake watershed has developed, and population in the area has rapidly increased. Hence, loads on the land become heavy, and environmental issues become serious and vital. Some lake coasts are reclaimed to sustain the increasing population, thereby causing continuous reduction of the lake area and shrinkage of the vegetation cover in the Taihu Lake watershed at a large scale. Pollutants easily penetrate into water and lake through soil erosion because of dense distribution of ditches and ponds in the Taihu Lake watershed (Wan et al. 2013). In May 2007, cyanobacteria bloom in Wuxi caused a drinking water crisis, thereby intensifying environmental issues (see Fig. 13.1). Generally, all government levels have given

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Fig. 13.1 In May 2007, cyanobacteria bloom in Wuxi (photograph taken by Jianfeng Zhang)

significant attention to water environment management in Taihu Lake by conducting various measures, such as the ninth 5-year plan of water pollution prevention in Taihu Lake and the overall plan for comprehensive management of water environment in the Taihu Lake watershed; these strategies adopt source control, pollutant interception, ecological restoration, and other means to comprehensively and systematically control pollution (Yin and Zhu 2010; Wang et al. 2008). An effective biological measure is the construction of protective forests (Feng et al. 2010), which can remove nitrogen and phosphorus and prevent non-point source pollution (Wu et al. 2011). Hence, the area of water source conservation forests must be increased for the improvement of water quality of inflow rivers and Taihu Lake and for alleviation of eutrophication in the lake (Niu et al. 2013).

13.1 Introduction

Native deciduous trees that can conserve water were selected to build protective forests in Taihu Lake in 2007. These protective forests were constructed in Yixing along the lake shore in 2008; the landscape exhibits 40 km length and 200 m width and covers an area of 8 km^2. In 2009, *Ginkgo biloba*, *Camptotheca acuminate*, and *Pterocarya stenoptera* were planted in strips or group-mixed forests, covering a total area of 20 km^2. In 2010, forest construction focused around four sides by using these tree species. Along the Taihu Lake, about 5 km of the protective forests was completed and covered an area of 12 km^2. By the end of 2010, the newly forested land expanded to 56.67 km^2 in Yixing; the expanded area included 40 km^2 Taihu Lake landscape protective forests, 13.33 km^2 economic forests (including cash trees, bioenergy forests), and 3.33 km^2 timber forest. The forest coverage increased by 2.78 % and reached 31.38 %. Meanwhile, the landscape coverage for villages reached 38 % (see Figs. 13.2, 13.3, 13.4, and 13.5).

All government levels and people living around the lake show considerable concern on the improvement effect of the large area of forest construction on the water environment in the Taihu Lake watershed. This issue is an important scientific topic and was therefore investigated in the present study.

Fig. 13.2 Trees are planted along channels connected into Taihu Lake (photograph taken by Jianfeng Zhang)

Fig. 13.3 Trees are planted along four sides (photograph taken by Jianfeng Zhang)

Fig. 13.4 Trees are planted along Taihu Lake banks (photograph taken by Jianfeng Zhang)

Fig. 13.5 Economic trees are planted (photograph taken by Jianfeng Zhang)

13.2 Description of the Test Plot

Yixing city in Jiangsu Province was selected as the test plot. This area is located in the south of Jiangsu and west of Taihu Lake at 31°29′28.97″ to 31°18′42.00″ north and 120°1′33.20″ to 119°55′55.30″ east and covers a total area of 1996.6 km^2. The Taihu Lake watershed covers an area of 242.29 km^2 in Yixing. With the hilly and plain polder areas in the south and north, respectively, Yixing shows a high trend in the south and a low trend in the north. The area can be divided into three topographic units, namely low mountains, hills, and plains, and belongs to northern subtropical monsoon climate, which features four distinctive seasons, such as full sunshine, and long frost-free season. The average annual temperature is 16.5 °C, the annual duration of sunshine is 1761.1 h, and the average annual rainfall is 1264.1 mm. Soils are mainly paddy in the plain and polder area, lacustrine clay and dark alluvial soil in the Taihu Lake basin, and yellow–brown and red in hilly areas in Yixing. The natural vegetation of the area is mainly the northern subtropical evergreen deciduous and broadleaf mixed forest, with coverage of 28.03 %.

13.3 Materials and Method

13.3.1 Soil Sample Collection and Determination

Soil samples were collected in farmlands near Wuxi, Dapu, Shaoxiang, and Baidu channels. At each sample collection point, surface soil samples (0–20 cm) were collected through serpentine distribution method according to the principle of randomness, equal quantity, and multiple points (a total of 10 points). Three repetitions were set in each sample profile (three soil samples per point). Soil was divided using a circular knife to determine bulk density, porosity, and water-holding capacity (Li et al. 2010; Wen et al. 2011). Soil samples were air dried in the laboratory, and fine roots were eliminated. The samples were then ground and screened through nylon sieves (hole diameter: 2, 1, and 0.25 cm) for analysis.

Soil sample determination: pH was determined using a pH meter by dipping the dried soil sample (10 g), which was screened through 2 mm sieve, into 25 mL of deionized water. Mechanical composition was determined using the screened soil sample through hydrometric method. Organic matter content was determined using the potassium dichromate oxidation with outside heating. Total nitrogen content was determined with semi-micro Kjeldahl nitrogen determination. Total phosphorus content was determined using sodium hydrogen carbonate fusion Mo–Sb colorimetric method. Available phosphorus content was determined with sodium hydrogen carbonate solution–molybdenum blue colorimetric method. Total potassium was determined with hydrofluoric–perchloric acid digestion combined with flame photometry. Available potassium was determined with 1 mol/L ammonium acetate extraction through flame photometry method (China Forestry Press 1991). Microbial biomass was determined with chloroform fumigation–incubation method (Jenkinson et al. 1990). The standard soil sample [following GBW07403 (GSS-3)] was purchased from the State Center for Standard Matter and used to calibrate the determined values of the chemical indices.

13.3.2 Survey of Vegetation Coverage and Plant Diversity

The research area was divided into forested lands and farmland. The species of wild herbaceous plants in the protective forest belts and neighbor farmlands were investigated through visual observation. The plants were statistically classified. The community distribution and structural composition of plants in the protective forest belts and farmlands approximated the species composition of regional herbaceous plant communities. The investigation was performed in October 2009 and May 2010.

13.3.3 Determination of Surface Runoff

In the study area, the lands were divided into protective forests and farmlands. Soil samples were collected from protective forests and farmlands through the cutting ring method and used to determine water-holding capacity and total porosity of soils in the laboratory. At the same time, the soil profile was dug to collect soil samples, and mechanical composition was determined through hydrometric method in the laboratory. Three repetitions were performed for each channel and land variety. Surface plant coverage was estimated through field measurements (Luo et al. 2002). Surface runoff was determined with the curve number method (CN). The calculation method is shown below:

$$Q = \frac{(p - 0.2S)^2}{p + 0.8S} \quad (13.1)$$

$$S = \frac{25400}{CN} - 254 \quad (13.2)$$

where Q is the actual runoff (runoff depth, mm), P is the rainfall amount (mm), S is the possible holdback (infiltration capacity, mm), and CN is a dimensionless comprehensive parameter that reflects the watershed features before raining. The CN value can be determined according to the CN value table, which is based on the condition of land utilization and soil classification in the test area and with reference to other domestic research results. High CN values result in low S and high Q, as well as easy generation of the runoff. The product of the surface runoff depth (Q, mm) and regional surface area (area, mm^2) is the regional surface runoff amount (V, mm^3).

13.4 Results and Analysis

13.4.1 Soil Condition Change

Texture is a stable soil index that significantly influences soil structural indicators, such as bulk density, porosity, and water content, as well as soil functions, such as air permeability, water permeability, and fertility. Sandy soil in the research area contains 89.26 % sand, 3.31 % powder, and 7.43 % clay. Soil was mainly composed of fine sand, with minimal amounts of sandy mud; thus, soil was not conducive to moisture and fertility preservation.

Soil bulk density, porosity, and permeability directly reflect soil firmness, structure/aeration, and permeability. The results showed (see Table 13.1) the following: the average bulk density of soil in the research area was 1.25 ± 0.16 g/cm^3, with a variation coefficient of 12.8 %; hence, the soil was suitable for plant growth. The average total porosity (V %) was 41.18 ± 0.05 %, with a variation coefficient of 12.2 %. The average capillary porosity (V %) was 33.91 ± 0.05 %, with a variation coefficient of 14.71 %. The average non-capillary porosity (V %) was 7.72 ± 0.02 %, with a variation coefficient of 25.91 %. Total and non-capillary porosities were low, whereas capillary porosity was moderate, which was consistent with the result that the mechanical composition of the soil was mainly sand. Field moisture capacity is a physical property of soils and is the upper limit of the available water of plants; this parameter is related to soil structure, texture, organic matter content, and land utilization condition. The average field moisture capacity of the research area (Table 13.1) was 27.45 ± 0.05 %, which

Table 13.1 Physical property of soils

Statistics	Bulk density (g/cm^3)	Maximum water-holding capacity (%)	Capillary water-holding capacity (%)	Minimum water-holding capacity (%)	Total porosity (*V* %)	Capillary porosity (*V* %)	Non-capillary porosity (*V* %)
Minimum value	1.05	27.45	23.02	20.49	32.24	25.55	5.59
Maximum value	1.48	45.18	36.36	33.61	47.66	39.11	10.08
Average	1.25	33.36	27.45	25.13	41.18	33.91	7.27
Standard deviation	0.16	0.07	0.05	0.05	0.05	0.05	0.02

was higher than the average level of the field moisture capacity of sandy soil. The soil exhibited strong water-holding capacity, thereby indicating that the soil particles were integrated with organic matter, resulting in the satisfactory soil structure in the study area.

Soil pH is an important chemical property of soils and comprehensively reflects soil conditions, physical and chemical properties, and fertility characteristics. Soil pH is also an important indicator for dividing soil types and evaluating soil fertility. The average pH of soil in the research area was 5.95 ± 0.63, with a variation coefficient of 10.59 %; thus, soil was considered acidic (see Table 13.2). According to the soil nutrient classification standard of the second national soil census, the contents of organic matter, total nitrogen, and total phosphorus in the soil were at medium levels; available phosphorus was at extremely high levels, and available potassium was at high levels (see Tables 13.2 and 13.3) in the research area. Generally, soils contain abundant total potassium. In the test area, the total potassium content was at high levels. The spatial variation coefficients of organic matter, total nitrogen, total phosphorus, available phosphorus, total potassium, and available potassium contents in soil were 37.33, 38.2, 43.5, 92.16, 50.81, and 105.33 %, respectively. Hence, the contents of organic matter, total nitrogen, total phosphorus, and total potassium of soil in the research area were evenly distributed, whereas available phosphorus and potassium contents were extremely unevenly distributed. Data analysis showed that available phosphorus and potassium contents had two extremely high values at individual points, reaching 207 and 406 mg/kg, respectively. The maximum amounts of available phosphorus and potassium were 30 and 17 times higher than the corresponding minimum values and were higher than those of organic matter, and total nitrogen, phosphorus, and potassium contents (about four times). Artificial fertilization may be the main reason for the uneven spatial distribution of nutrients and their extremely high values. The microbial biomass of soil was high at 206.83 ± 135.28 mg CO_2–C/kg dm on average, which indicated the presence of rich microbes in the soil and high potential activity.

Table 13.2 Chemical property of soils

Statistics	pH	Organic matter (g/kg)	Total nitrogen (g/kg)	Total phosphorus (g/kg)	Available phosphorus (mg/kg)	Total potassium (g/kg)	Available potassium (mg/kg)
Minimum value	4.94	6.5	0.57	0.34	6.83	3.37	23.00
Maximum value	7.22	30.90	2.33	1.52	207.00	15.40	406.00
Average	5.95	19.93	1.34	0.74	63.35	6.03	79.87
Standard deviation	0.63	7.44	0.51	0.32	58.38	3.06	84.13

Table 13.3 Soil nutrient classification standard

Nutrition level	Organic matter (g/kg)	Total nitrogen (g/kg)	Total phosphorus (g/kg)	Available phosphorus (mg/kg)	Available potassium (mg/kg)
Extremely low	<6	<0.50	<0.2	<3	<30
Low	6–10	0.5–0.75	0.2–0.4	3–5	30–50
Medium to low	10–20	0.75–1.0	0.4–0.6	5–10	50–100
Medium to high	20–30	1–1.5	0.6–0.8	10–20	100–150
High	30–40	1.5–2	0.8–1.0	20–40	150–200
Extremely high	>40	>2	>1	>40	>200

13.4.2 Influence of Establishing Protective Forests on Plant Diversity

After surveying the farmlands and protective forest lands in the research area, 64 herbaceous plants, which belong to 21 families and 55 genera, were obtained; among these plants, Gramineae and Compositae plants contained the highest number of species (see Table 13.4). The common plants of Gramineae included 17 species, such as *Avena fatua*, *Setaira viridis*, *Echinochloa crus-galli*, *Alopecurus aequalis*, and *Eleusine indica*. The common plants of Compositae included 17 species, such as *Conyza canadensis*, *Solidago decurrens*, *Artemisia argyi*, and *Cirsium setosum*. These two families of plants accounted for 53.13 % of the total species, thereby forming a large majority of herbaceous plants. Other species included 6 plants of *Polygonaceae*, 3 plants of *Chenopodiaceae*, 3 plants of *Labiatae*, 2 plants of *Leguminosae*, 22 plants of *Amaranthaceae*, and 1 plant of each other families.

Various wild herbaceous plants inhabited the protective forests. The community structure was developed toward diversification and complication, and biological diversity was significantly improved in protective forests than that in farmlands. The structures of herbaceous plant communities varied significantly between the shade and light areas in the forests. In the shade area, the species were mainly shade-tolerant herbaceous plants (*C. canadensis*, *Erigeron annus*, *clover*, and *A. argyi*), which were distributed in patches. In the areas with full light, such as forest gap, forest edge, and outside of the forest belts, *C. canadensis*, *clover*, *Roegneria kamoji*, and *A. aequalis* were the dominant species. The community structure comprised multiple species of mixed growing plants. In farmlands, herbaceous plants had no evenly distributed strip community structure. Common herbaceous plants included *Geranium carolinianum* L., *E. crus-galli*, and *Veronica persica* without obvious dominant species. These plants were distributed sparsely in

Table 13.4 Plant species composition in the area

Family	Genus	Species	Family	Genus	Species	Family	Genus	Species
Gramineae	16	17	Plantaginaceae	1	1	Geraniaceae	1	1
Compositae	15	17	Euphorbiaceae	1	1	Solanaceae	1	1
Polygonaceae	3	6	Hemp	1	1	Rubiaceae	1	1
Chenopodiaceae	1	3	Verbenaceae	1	1	Caryophyllaceae	1	1
Labiatae	3	3	Ranunculaceae	1	1	Scrophulariaceae	1	1
Leguminosae	1	2	Cruciferae	1	1	Oxalidaceae	1	1
Amaranthaceae	2	2	Rosaceae	1	1	Convolvulaceae	1	1

line or patch along the roads or ditches in a few numbers. This distribution pattern was due to the fact that protective forests provided suitable diversified habitat conditions for plants; thus, herbaceous plants had wide variety and high biodiversity. In farmland habitats, the species of herbaceous plants were relatively rare because of the application of traditional farming practices, such as physical mowing and herbicide application. The results implied that protective forests can effectively improve the regional niche and can significantly increase plant species diversity.

13.4.3 Effects of Tree Planting on Surface Runoff

The surface runoffs of different lands around the protective forest lands were studied. Soil permeability under different land use ways was determined with CN method. The results showed that soil permeability considerably varied under 16 land use ways. The CN values of open land and waste land were low, whereas those of streets and roads were the highest. However, the soil permeability of forested land with high vegetation coverage and grassland was low. Table 13.5 shows the CN values of different soil types and land use ways.

The physical properties of soil were not significantly different between protective forests and farmlands in the research area; these properties included maximum

Table 13.5 *CN* values of different soil types and land use ways under equal moisture state

Land use ways	Soil permeability			
	A	B	C	D
Open land, wasteland (grass coverage > 75 %)	39	61	74	80
Open land, wasteland (grass coverage 50–75 %)	49	69	79	84
Wasteland (bare land)	76	85	94	100
Arable land (without water preservation measure)	72	81	88	91
Arable land (with water preservation measure)	62	71	78	81
Pasture or mountain (barren)	68	79	86	89
Pasture or mountain (fertile)	39	61	74	80
Grassland (coverage > 75 %)	39	61	74	80
Grassland (coverage 50–75 %)	49	69	79	84
Grassland (coverage < 50 %)	68	79	86	89
Forested land (scattered)	45	66	77	83
Forested land (medium dense)	36	60	75	80
Forested land (highly dense)	25	55	70	77
Street and road (muddy land)	72	82	87	89
Street and road (stone paving)	98	98	98	98
Street and road (cement)	100	100	100	100

Note A is as permeable as sandy soil; *B* is as permeable as sandy loam and light-soil land; *C* is as poorly permeable as medium loam soil; *D* is as impermeable as cement and ground paved with stones

Table 13.6 Basic physical properties of soil under different land use ways

Soil property		Maximum water-holding capacity (%)	Capillary water-holding capacity (%)	Total porosity (*V* %)	Sand particle (%)	Powder (%)	Clay particle (%)
Protective forest	Mean	32.55	26.54	42.09	89.41	3.04	7.55
	Standard deviation	0.05	0.04	0.01	0.01	0.01	0.01
Farmland	Mean	33.63	28.18	38.50	88.97	3.86	7.17
	Standard deviation	0.06	0.07	0.09	0.01	0.01	0.01

water-holding capacity, capillary water-holding capacity, total porosity, and particle content. Mechanical component analysis showed sandy soil in both protective forests and farmlands had good permeability (as Table 13.6 shown).

The physical properties of soil varied under different types of land use. The basic physical properties of soil under land use in protective forests and farmlands were studied by comparing their maximum water-holding capacity, capillary water-holding capacity, total porosity, and sand and clay particle contents. The results showed that soil properties changed; in particular, capillary water-holding capacity and total porosity significantly changed, whereas those of the sand particles exhibited minimal changes. Changes in land use ways induced changes in the basic physical properties of soil. Construction of protective forests can alter the total porosity and compositions of sand and clay particles.

Surface runoff after rainfall was analyzed by calculating the annual surface runoff depths of protective forests and farmlands, with the average annual rainfall (p = 1205.3 mm), soil texture (sandy soil), forest land (medium density), grass (coverage > 75 %), and arable land (no water preservation measure) as the basis for the CN method. The *CN* values of soils in the protective forests and farmlands were 36 and 72, respectively. After substituting the *CN* values into Eq. (13.2), the maximum possible holdup amounts (S) of soil in the protective forests and farmlands were obtained, with values of 451.56 and 98.78, respectively. After substituting S and p into Eq. (13.1), the surface runoff depths (Q) of the protective forests and farmlands could be obtained, with values of 793.59 and 1094.36 mm, respectively; these values also accounted for 65.84 and 90.8 % of the average annual rainfall, respectively. The surface runoff of farmlands was significantly higher by 38 % than that of protective forests. This result indicated that protective forests played an important role in controlling surface runoff and reducing water and soil loss, as well as nutrient migration.

13.5 Discussion and Conclusions

Prior to construction of protective forests, the lands were used as farmlands. Soil condition in the farmlands was studied. The results showed that sandy soil in the test area was suitable for plant growth; this soil had an average bulk density of 1.25 ± 0.16 g/cm^3, with low total and capillary porosities and moderate capillary porosity. The soil had high field moisture capacity, good structure, and high water-holding capacity. Soil particles were integrated with organic matters, and the soil was acidic. The contents of organic matter, total nitrogen, and total phosphorus were at medium levels; meanwhile, the contents of available potassium, total potassium, and available phosphorus were at slightly high, high, and extremely high levels, respectively. Thus, nutrients were unevenly distributed. Microbes were rich in the soil with high potential activity. The overall properties of the soil showed that it was suitable for plant growth, which provided a prerequisite for ecological protective forest construction. The contents of available and total potassium in the soil were at high levels. Protective forests could absorb abundant elements from soils and thus function in source reduction and sink increase. Constructing lake bank protective forests and increasing vegetation community coverage could be used to effectively adsorb excessive nutrients and weaken the non-point source pollution of the watershed.

Various herbaceous plants were found in the protective forests. A total of 21 families and 64 species of herbaceous plants were recorded during the field survey. Gramineae and Compositae contained 17 each, thereby indicating their dominance. The dominant community was not evident in farmlands; however, in the protective forests, the dominant plants included *C. canadensis*, *A. argyi*, and *E. annus* were formed, thereby implying that the forest ecosystem was stable. The herbaceous plants were scattered and had no dominant species and stable community structure because of the adoption of traditional farming practices in farmlands, such as physical cutting or herbicide use. The protective forests contained abundant species, and the community structure was gradually restored and optimized. In the shading area, shade-tolerant herbaceous plants (*C. canadensis*, *E. annus*, *clover*, and *A. argyi*) were the dominant species in the community structure. These species were distributed in the shading area of the protective forests in patches. In areas with full light, such as forest gap, forest edge, and outside of the forest belts, the community structure was mainly a mixture of various species. The protective forests effectively improved the regional niche and significantly increased species diversity.

After touching the ground, the rain that cannot penetrate the soil will cause surface runoff. The runoff dissolves a large number of soluble nutrients, which penetrate into the soil to form the pollutants (Li et al. 2013). Surface runoff in protective forests was significantly lower than that in farmlands. Thus, construction of protective forests is an effective technique for reducing the surface runoff of soil, inhibiting the penetration of pollutants into the soil, and increasing soil fertility (Bai et al. 2010). The mechanical composition of soil is a stable index, which remains unchanged in the human timescale. Improving the soil texture through human intervention via increasing permeability is not feasible from ecological perspective because of heavy projects and high cost. Thus, the most effective method is increasing soil permeability to the maximum extent and reducing surface runoff by using plants. In this project, ecological protective forests were constructed within 50 m to the lake shore areas on both sides of inflow channels to improve soil structure and reduce surface runoff and soil nutrient load. Trees were dominant in the artificial structure of the protective forests and were supported with shrubs. The forests were constructed at medium density, with a spacing of 3 m $\times$ 3 m for trees and 1 m $\times$ 1 m for shrubs. Subsequently, the forests were enclosed. After 1 year, a community structure of wild herbaceous plants gradually recovered and optimized in the protective forests, thereby increasing species diversity. The grass coverage in the protective forests was calculated using the field measurement method. Except for the roads, the surface of the protective forests was nearly all covered with wild herbs, with coverage of over 95 %. The coverage of the farmlands near the protective forests was low, with an annual average of 50 %. Moreover, no water preservation measure existed, thereby leading to serious surface runoff and low

Fig. 13.6 Complex forest structure helps to prevent from soil and water erosion (photograph taken by Jianfeng Zhang)

biodiversity issues. Thus, constructing protective forests could be a low-cost but efficient ecological restoration technique for improving soil condition, reducing surface runoff, improving local niche, and increasing species diversity. This technique can also be employed in the environmental management of the watershed.

Generally, protective forests were constructed to improve the soil environment. Sandy soil in the research area is composed of sand particles, which fail to preserve water and fertilizer. Soil erosion is a factor that intensifies soil and water pollution. Increasing vegetation coverage and improving forest structure stability can effectively reduce soil erosion. Grass and crop cover exerted satisfactory effects on water and soil preservation. Increasing forest coverage and constructing multilayer forest structures, such as tree, shrub, and herb layers, can intercept rainfall to different extents, prevent surface runoff, and improve the preservation of water and soil (see Fig. 13.6). Furthermore, increased vegetation coverage is helpful to increase the contents of organic matter and green manure in soils. Regular fertilization in a small quantity is conducted to improve soil fertility. In summary, increasing forest vegetation coverage in the Taihu Lake watershed can increase plant diversity, effectively improve the ecological environment along the coast of Taihu Lake, and ensure safety of water quality.

References

Bai FM, Tian DL, Fang X et al (2010) Nutrient concentrations in soil and plants of protective forests in Western Bank of Dongting Lake. J Ecol 30(21):5832–5842

Feng LJ, Feng L, Sun DZ et al (2010) Study on removing nonpoint source pollutants-nitrogen and phosphorus by vegetation of protection forest system. J Harbin Univ Commer: Nat Sci Ed 26 (5):548–550

Jenkinson DS, Andrew SPS, Lynch JM et al (1990) The turnover of organic carbon and nitrogen in soil (and discussion). Philos Trans R Soc Lond B Biol Sci 329(1255):361–368

Ji XL, Gao JF, Zhao GJ (2006) Impacts of 20-year social and economic development on the trend of aquatic environment of the Taihu Basin. Resour Environ Yangtze Basin 15(3):298–302

Li Z, Wu PT, Feng H et al (2010) Simulated experiment on effects of soil bulk density on soil water holding capacity. Acta Pedol Sin 47(4):611–620

Li ZB, Zhang JF, Chen GC et al (2013) Research on the pollutant characteristics in the surface runoff in Fushi Reservoir, Anji County. J Water Soil Conserv 27(3):90–94

Luo LF, Zhang KL, Fu SH (2002) Application of runoff curve number method on loess plateau. Bull Soil Water Conserv 3:58–61

Niu Y, Yu H, Zhang M et al (2013) Impact of typical land-using patterns on water quality of rivers in lake Taihu Watershed. Res Environ Yangtze Basin 22(2):205–211

Science and Technology Department (1991) Ministry of Forestry of the PRC. Collection of Standards in the Forestry Industry (3). China Forestry Press

Wan YJ, Wang WL, Zhou F et al (2013) Characteristics and estimation of rural sewage pollutants abatement by surface soil in typical rural regions of Taihu Lake Basin. J Ecol Rural Environ 29 (6):796–803

Wang YY, Sun Y, Zhao YW (2008) Current status and prevention measures of agricultural non-point source pollution in Taihu Lake Basin of Jiangsu Province. Acta Agric Jiangxi 8:118–121

Wen L, Liu JL, Xi Y et al (2011) Analysis on soil physical properties of the old trees in Beijing. Res Soil Water Conserv 5:175–178

Wu DM, Xue JF, Wu YB (2011) Reviews on effects of ecological shelterbelts on alleviating non-point source pollution of nitrogen. J Nanjing For Univ: Nat Sci Ed 35(6):134–138

Yin RY, Zhu XD (2010) Countermeasures of Taihu Lake water pollution control in Jiangsu Province. Environ Prot Sci 36(3):93–95

Zhang SB, Wang YP (2007) Analysis of the environmental influence of intensive agriculture in Taihu Lake watershed. Environ Prot 29–31

Chapter 14
Control of TN and TP by the Pond and Wetland Integrated System

Abstract Agricultural non-point source (NPS) pollution is an important pollution source and has been a serious threat to water quality safety; by contrast, point source pollution has been gradually controlled. In this chapter, we studied the control effect of artificial pond–wetland coupled systems on the reduction in total nitrogen (TN), total phosphorus (TP), and other pollutants in the Shenxi River watershed in Anji County by continuous sampling and monitoring. Results showed that from May to October in 2012, TN concentration was 3.7–6.4 mg/L, the TN removal rate was 9.9–63.4 % for artificial water ponds at the mouth of Zhongzhang River, and the removal efficiency of TN was strongly influenced by water TN concentration. For the artificial channel connected to the Zhongzhang River, water TN concentration was within the range of 2.5–5.1 mg/L, the TN removal rate was 5.0–48.1 %, and all TP removal rates were more than 30 % for the artificial ponds in Hongcun and Shenxi villages. At high water TP concentration of the artificial ponds, the removal effect was improved and the purification efficiencies of TN and TP were satisfactory in Hongcun village and Shenxi River downstream wetlands. The TN removal rate reached 25.0–96.0 %, whereas the TP removal rate was within the range of 21.8–98.1 %. Generally, the annual average TN removal rate was 60.4 % for the combined system of artificial pond–wetland, and the highest rate reached 86.8 %; meanwhile, the average TP removal rate was 78.6 %, and the highest rate reached 94.9 %. Therefore, the effect of combined artificial wetland system on nutrient reduction was rather good and helpful for NPS pollution management in the Shenxi River watershed.

Keywords Small watershed · Pond–wetland combined system · Agricultural non-point source pollution · TN · TP · Nutrient reduction · Removal rate · Purification efficiency · Artificial pond · Artificial wetland · Water quality safety

Environmental pollution includes point source and non-point source (NPS) pollution. As point source pollution has gradually decreased in recent years, NPS pollution is the first impact factor of water pollution and tends to be worse in the Taihu Lake watershed. About 60 % of water pollution originates from NPS pollution as such,

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effective management of NPS pollution has obtained increased attention from all levels of the government and people (Wen et al. 2004; Yu et al. 2010). Research indicated that 30–50 % of the earth surface has been affected by NPS pollution in different degrees, of which agricultural NPS pollution is the main source of NPS pollution. The loss of N and P from soils mainly causes eutrophication, which is a serious threat against water quality and environmental safety (Zhao et al. 2010). In contrast to point source pollution, agricultural NPS pollution is difficult to control and prevent because of its randomicity, universality, hysteresis, and complexity (Yu et al. 2010). Currently, the mechanism of effectively controlling agricultural NPS pollution requires further investigation. Nevertheless, measures, such as artificial wetlands, pre-dams, buffer zones, lake–water ecotone, and agro-ecological project, have been widely applied (Yin and Mao 2002; Chai et al. 2006; Chun et al. 2010).

14.1 Introduction

As a typical ecological wastewater treatment, the combined artificial pond–wetland system has played an important role in controlling NPS pollution; this system also shows significant effect on improving rural water quality (Liu 1997; Coveney et al. 2002; Wang et al. 2008). Artificial wetlands can improve surface water quality and remove total nitrogen (TN) and total phosphorus (TP) of water; this effect is closely related to several factors, such as nitrogen and phosphorus concentration in inflow water, hydraulic retention time, and water temperature. Reducing agricultural NPS pollution load depends on two factors, namely, ecological interception of exogenous pollutants and ecological extraction of endogenous pollution loads (Liu et al. 2004a, b; Yang et al. 2008). Obviously, the combination of different types of wetland systems can play distinct roles based on the features of various wetlands; thus, the removal effect of the combination of composite systems on pollutants is stable, and the efficiency of wastewater treatment is high (Liu et al. 2004a, b; Cui et al. 2009). In practice, the combined pond–wetland system is widely applied because it is characterized with high removal rate of pollutants, low management intensity, low operating cost, easy conduction, and other beneficial features (see Figs. 14.1, 14.2 and 14.3). Thus, in terms of nitrogen and phosphorus reduction and agricultural NPS pollution control, the combined pond–wetland system is one of the most advantageous and commonly used agricultural ecological engineering technology (Shan et al. 2006).

Watershed is a region covered by river, lake, ocean, or its catchment areas; this region is also a "nature–society–economy" complex system (Chen and Ouyang 2005). The watershed hydrological phenomenon is related to watershed characteristics, including land use systems, vegetation types, and other ecological processes; vegetation types have a significant impact on the "source" and "sink" of nitrogen, phosphorous, and other biogenic elements (Hammer 1992; Chen 1996; Wang et al. 2005). In the Taihu Lake watershed, some combined natural pond–wetland systems exist; additionally, crisscrossed rivers, channels, and ponds, which

Fig. 14.1 Artificial wetland in Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 14.2 Artificial pond to reduce TN and TP (Photograph taken by Jianfeng Zhang)

Fig. 14.3 Artificial canal to remove pollutants (Photograph taken by Jianfeng Zhang)

comprise intricate networks, provide a fine infrastructure for the implementation of a combined pond–wetland system to control agricultural NPS pollution.

The Shenxi River watershed is located in Anji County in Zhejiang province; this watershed is an important water source and located upstream of the Laoshikan reservoir; as a major source of Huangpu River, the Shenxi River watershed is a major drinking water resource source for Shanghai residents. Factors such as chemical fertilizers, pesticides, livestock feces, sewage, surface runoff, and soil erosion by rainfall, irrigation, and leaching have caused NPS pollution, which has been a serious threat to the water quality of the Laoshikan reservoir and downstream (Li et al. 2008; Liu 2009; Zhang et al. 2011). The impact of agricultural NPS pollution on ecological environment is extensive in the area because its occurrence is random, pollutant sources and discharge points are not fixed, emission is intermittent, and pollution load has large variations in spatial and temporal scales. Compared with point source pollution, monitoring, control, and treatment of agricultural NPS pollution are more difficult.

To date, agricultural NPS pollution is widespread in the Shenxi River watershed and has been an important source of pollution that affects water quality and environment. Thus, study on NPS pollution control and governance must be performed. Relative research on TN and TP reduction and agricultural NPS pollution control is very few in this region. In view of the study status of agricultural NPS pollution in

Anji Shenxi River watershed, various techniques are available; these techniques include the use of artificial pond system combined with wetlands and nearly natural forest ecosystems, implementation of hierarchical control of runoff, and layered purification of pollutants. In this research, the effect of the combined artificial pond–wetland system on agricultural NPS pollution was probed under specific climate and soil conditions of the watershed. The removal efficiency of TN and TP by the integrated system was analyzed. Chemical oxygen demand (COD) change and characteristics were also measured. The effect of TN and TP concentration in the inlet and outlet of the river on removal efficiency was approached through sentinel sampling and analysis in Zhongzhang River and Shenxi River.

14.2 Test Plot Description

The study area is located in Anji County, Zhejiang province, which is in northwest of Zhejiang province, north of Tianmu Mountain, and located between 119°14″–119°53′ E and 30°23′–30°53′ N. The land area covers 1886 km^2 and has a population of 460,000. This area is a mountainous country, with a combination of mountainous, hilly, downlands and plains, and other landforms. The Shenxi River watershed is an important water source for the Laoshikan reservoir, which is about 18 km long; this watershed has an area of 42 km^2, and the average annual flow is about 0.37 million m^3. The Shenxi River watershed has different functions, such as irrigation, drainage, flood control, water supply, power generation, and others. The watershed area belongs to the mid-latitude north subtropical monsoon zone with four distinct seasons, mild climate, and abundant rainfall. The average annual rainfall is 1861.2 mm, and rainfall is unevenly distributed, which is mainly concentrated in April to October yearly and accounts for 77.32 % of annual precipitation. Red soil is dominant in the watershed, with a small amount of yellow–brown soil and mountain meadow soil. Paddy soil is distributed mainly at fields below altitude of 250 m or in both sides of the river mouth of Shenxi, which is the product of cultivation activities. The average soil nutrient contents are as follows: 3.66 and 0.214 % organic matter and nitrogen, respectively, as well as 7.18 and 48.1 mg/kg of available phosphorous and potassium, respectively. Farming practice is ordinary and not intensively managed in the area. Generally, NPS pollution was caused by agricultural production and human activities. In the watershed with widespread pollutants accumulated along the river, water quality is under the threat of eutrophication (see Fig. 14.4). When the pollution is serious, three indicators, namely, TN, NH^{4+}–N, and TP, are at 1.71, 0.81, and 0.07 mg/L in the reservoir, respectively. According to the National Surface Water Quality Standards (Zhang et al. 2011), such water is under class III, which meant that the water could not be drunk directly by people.

Fig. 14.4 Water pollution in Shenxi River (Photograph taken by Jianfeng Zhang)

14.3 Materials and Methods

In this watershed, the pond layout and positioning were on both sides of agricultural areas, linked with streams and combined with the existing canal system. On-site topography and runoff occurrence site were also considered. The pond was also an irrigation facility, with a depth of about 2 m, and contains inlet, as well as outlet for irrigation and overflowing. The inlet and outlet were connected with the canals for water flowing into and flowing out, respectively. A culvert valve was found at the irrigation outlet; thus, water can flow out by gravity when irrigation was needed; overflow outlet was located at the top, and the overflow canal was set below, which was connected with the receiving water body. The overflow canal was made as a form of artificial wetland to improve water purification capacity, and the depression land could be as large as an aquatic plant area, with a depth of about 0.5 m. Moreover, the existing canal system was utilized and improved to connect the upper and lower ponds. The artificial pond and canal–wetland system were constituted, with a canal width of 0.8 m; the inside height of the canal along the river shore, height near farmland side, and depth were 60, 45, and 45 cm, respectively. The system was considered monotony as an engineering technology. To date, the integrated system in the Shenxi River watershed overcame the previous shortcomings, and the ecological process was diversified; hence, the removal efficiency increased and the ecosystem was more stabilized.

Economic shrubs and grass were planted in pond slopes, whereas arbors and mesophanerophytes were properly scattered or clump-planted for landscape and soil fixing. Emergent plant communities were established in the inundation zone of the inside pond slope to create landscape and economic benefits, whereas plant communities, *Ustilago esculenta* Henn, aquatic plants, and aquatic herbs, were grown in the middle of the water, depression, overflow canal, and at the gully, respectively.

Adaptability, root system growth, distribution, amount of litters, nutrient uptake and storage, economic effects, and landscape characteristics should be considered for tree species selection. Accordingly, the following species could be applied in the watershed:

Arbors: *Pinus elliottii*, *Carya illinoensis*, *Sapium sebiferum*, *Toona sinensis* (A. Juss), *Liquidambar formosana* Hance, *Ginkgo biloba*, *Acer negundo* Linn., *Nyssa aquatica*, and *Eel bamboo*.

Shrubs: *Hibiscus hamabo* sieb et zucc, *Photinia serrulata* Lind., *Illicium verum*, *Lycium* sp., *Jasminum nudiflorum*, and *Cyperus alternifolius*.

Herbaceous flowers: *Canna indica*, *Iris tectorum*, *Hippeastrum rutilum*, and *Lycoris radiate*.

Ground cover: mainly wild ground cover plants.

Wetland subarea and water purification process: With the transformation of the original wetlands, natural subareas occur, such as wetland forest, emergent plant, floating plant, submerged plant, and other functional areas, depending upon the terrain and water level. Floating plant and submerged plant areas could be used as reserved areas when necessary; they could function at any time. In terms of the current water quality and requirement, they were not enabled temporarily. When water flowed through each functional area, water purification function would be strengthened through the synergy of each partition in the process.

With the completion of pond–wetland system, water began to run continuously in the system after plant transplanting and community building. This integrated system (see Fig. 14.5) as a whole was relatively stable, and continuous sampling and testing were started. Water quality monitoring was divided into two parts: the first part was for Zhongzhang River, as the water was influenced and polluted by human activity along the river, water quality began to deteriorate; since March

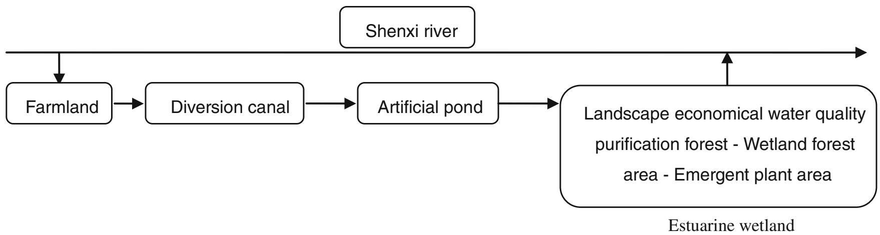


Fig. 14.5 Artificial pond, canal–wetland system diagram

2012, water quality monitoring based on sampling and testing in the main plots was performed, hence analyzing the spatial and temporal distribution of pollution in the river. The second part was for Shenxi River, which was the downstream of Hongcun village; under the influences of agricultural management, farmland irrigation, and drainage, pollutants went through riparian leakage, and surface runoff went into the river. During the project, part of water from farmland outflow was introduced into the artificial pond–canal system after preliminary purification through inflow of estuarine wetland to test removal effect. Subsequently, sampling was performed at the main monitoring points, i.e., agricultural water discharge outlet, inlet and outlet of pond–canal, filter belt of grass, aquatic plant communities, and inlet and outlet of some stands. From May to October of 2012, sampling was repeated at each monitoring point. All samples were collected with 3–6 repetitions, stored at low temperature, and analyzed within 48 h in the Research Institute of Subtropical Forestry of Chinese Academy of Forestry.

Determination method of testing indicators: COD measurement, TN, and TP were performed with dichromate method, alkaline potassium persulfate digestion with ultraviolet spectrophotometry and ammonium molybdate spectrophotometry, respectively (Wei et al. 2002). For data treatment and analysis, software SPSS18.0 and origin7.5 were used.

The pollutant removal rate was calculated as:

$$\mathrm{Re} = (C_1V_1 - C_2V_2)/C_1V_1 \times 100\,\%$$

where C_1 and C_2 are the concentration of pollutants in water when flowing into and flowing out, respectively; V_1 and V_2 represents the water volume flowing into and flowing out, respectively. If evapotranspiration loss is excluded, then $V_1 = V_2$.

14.4 Results and Analysis

14.4.1 NPS Pollutant Generation, Migration Law, and Temporal and Spatial Distribution

14.4.1.1 TN and TP Pollution Load Changes in Zhongzhang River Source

For water TN and TP change in Zhongzhang River source, the middle and downstream reaches based on sampling and analysis of the results were shown (Fig. 14.6). The water quality in the upstream of Zhongzhang River was generally much more stable; only in July and September, the quality was impacted by heavy rains' water quality, thus not so good; in other period, water quality indicators, such as nitrogen and phosphorus, were better than those for Class III, according to the National Water Quality Standard. However, nitrogen and phosphorus concentrations had fluctuations in the middle and downstream reaches of Zhongzhang

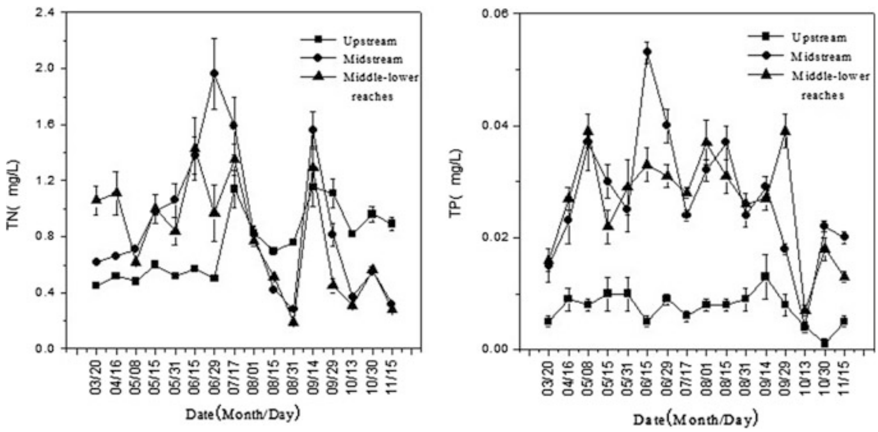


Fig. 14.6 TN and TP changes in upstream, middle, and downstream reaches of Zhongzhang River

River; TN and TP reached the peak value around June to July and in September; when the nitrogen and phosphorus concentrations rose to the highest, the water quality reached Class V (according to the National Water Quality Standard, Class V water is poor and cannot be used). The pollution was mainly caused by villagers and agricultural production activities in the upstream; the time was basically accordant for nitrogen and phosphorus reaching the peak, highest rainfall, and fertilizers and pesticide applications for farmland in the upstream.

With the presence of pollution sources along the inflow streams, the amount of TN and TP increased with the extended flowing process. Nevertheless, the monitoring result showed that TN load was in a downward trend in August and October in the middle and downstream reaches of Zhongzhang River, which might imply that the banks of the river could adsorb some nutrients and play water purification effect.

14.4.1.2 TN and TP Load Changes in Hongcun Village Farmland Drainage

After collecting samples, TN, TP, and COD in Hongcun village Shenxi River downstream farmland drainage were analyzed, and the results are presented as Fig. 14.7. TN concentration from farmland effluent was worse than that of Class V; TP concentration did not exceed that of Class V, except in May. In this region, TN emissions reached the peak in May and July; the TN concentration of farmland drainage in July reached 33.3 mg/L, and TP content reached 1.99 mg/L in May. Here, nitrogen and phosphorus concentrations were 16.7 and 5 times more than the value of Class V, respectively. Meanwhile, the rule of COD change from farmland drainage was similar to TN and TP; during the monitoring period, the farmland

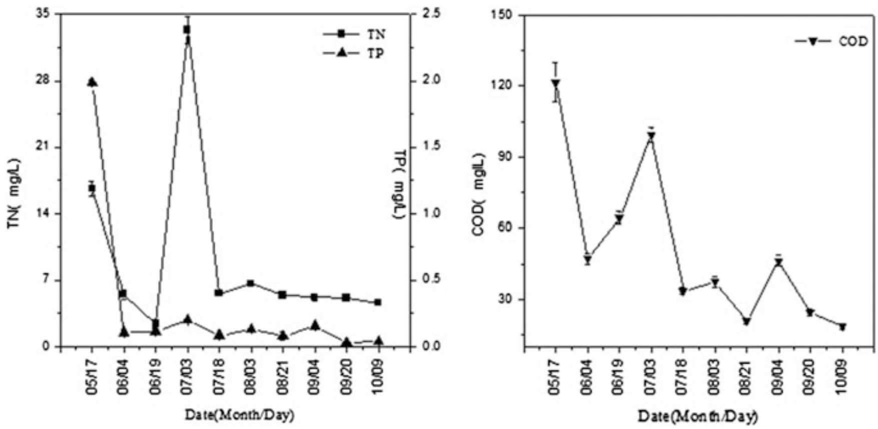


Fig. 14.7 TN, TP, and COD changes in Hongcun village Shenxi River downstream farmland drainage

drainage COD value was 51.4 mg/L on average, which was far beyond that of Class V. The peak value of COD appeared in May and July, which increased to 121.0 and 99.0 mg/L, respectively. In fact, the occurring time of farmland nitrogen and phosphorus emission peaks was in accordance with the period of fertilizer application and more organic pollutants mixed with rice paddy effluent, thereby resulting in a further deterioration of water quality.

14.4.2 Farmland Sewage Purification by Artificial Pond–Wetland System

14.4.2.1 Sewage TN Removal

From May to October of 2012, the TN removal efficiency for farmland sewage was determined in Hongcun village and Zhongzhang River artificial ponds. The results indicated that (Figs. 14.8 and 14.9) from May to October, the TN concentration showed fluctuations in Zhongzhang River artificial pond influent. Compared with other months, the TN concentration of artificial pond influent was low in mid-May and mid-June, which was about 3.7 and 2.2 mg/L, respectively; correspondingly, the TN removal rate by artificial pond was relatively low, which was only 9.9 and 14.5 % for mid-May and mid-June, respectively. Approximately, the TN concentration in Hongcun village artificial pond influent between May and June was rather low at 2.5 mg/L on the average; the TN removal rate by artificial pond was relatively low at 27.6 %.

However, between July and August, the TN concentrations increased in the two artificial pond influents, which were both higher than 5 mg/L; in Zhongzhang River

Fig. 14.8 TN change in Zhongzhang River artificial pond

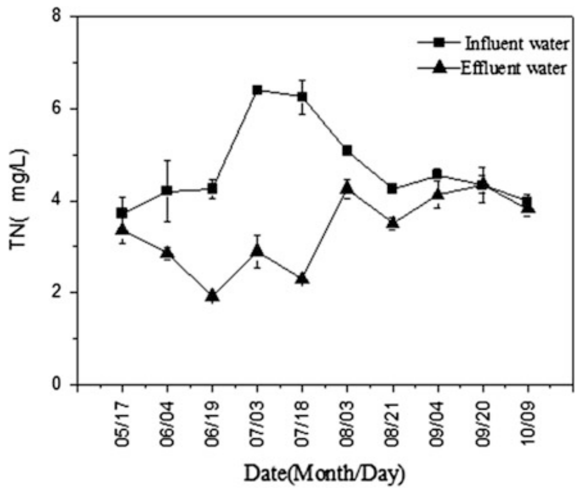
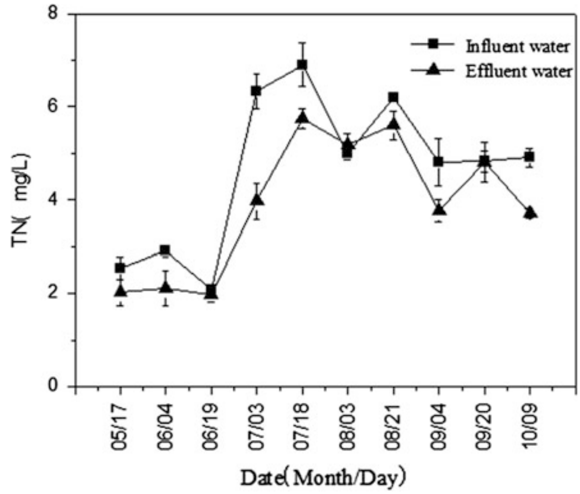


Fig. 14.9 TN change in Hongcun village artificial pond



and Hongcun village artificial pond influents, the TN concentration reached the highest at 6.4 and 6.9 mg/L, respectively; in this case, the TN removal rate by artificial ponds was also significantly higher than that in other months; in Zhongzhang River and Hongcun village artificial ponds, the TN removal rate reached the highest at 63.4 and 37.4 %, respectively. For such sewage with high nitrogen concentration, the removal efficiency could go high, which showed the superiority of the artificial pond on sewage treatment. When the sewage flowed into the pond, flowing slowed, and insoluble particles in sewage could be trapped down by precipitation and/or adsorption, so that water quality had preliminary purification; in addition, pond plants and microbes also had the effect of adsorption and decomposition on water pollutants.

With the above analysis, the artificial pond during July and August had much higher TN removal rate than that in May and September to October. The main reason for this result might be that when the temperature was high, the influent concentration increased, plants grew fast, and microbes became much more active; all these factors led to TN removal rate increased to some extent. Moreover, the TN concentration of the effluent was also affected by the change in water inflow rate. For the artificial ponds, it became slowly when water passed through, which was conducive to complete precipitation and pollutant absorption. This result showed that the artificial pond had some cushioning effects on pollutant concentration change; the higher water pollutants would result in better purification effect. Therefore, to control agricultural NPS pollution, artificial pond system could be established at the source area where pollutants had centralized emissions; thereby, sewage runoff could be retained, water be purified, and NPS pollution be reduced.

The TN removal rate of the artificial canal was analyzed in Zhongzhang River downstream from May to October of 2012 (Fig. 14.10). The TN concentrations from May to October in Zhongzhang River artificial canal influent had slight fluctuation, and the value was within the range of 2.5–5.1 mg/L. The TN removal rate in artificial pond effluent reached the minimum at 5 % in May, whereas it rose to the highest at 48.1 % in mid-June. Unlike the TN removal performance in artificial ponds for sewage, the artificial canal did not show the trend of regular removal rate increase with increased influent TN concentration, and the average removal rate was generally much more stable at 24 %. From July to early August, the TN concentrations in canal effluent were also higher than that in the influent, specifically in mid-July (Fig. 14.10). The TN concentrations in artificial canal effluent were much higher than those in the influent because heavy rains led to

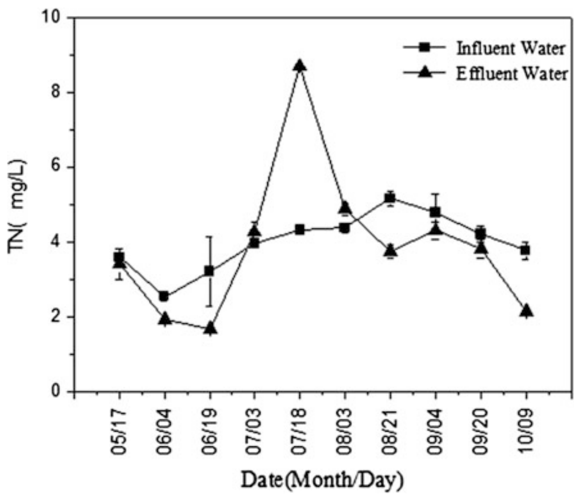


Fig. 14.10 TN change in Zhongzhang River artificial canal

increased water flow period; the part of the nitrogen adsorbed by the artificial canal was washed out of the canal, and the artificial canal was narrower and shallower than the artificial pond. When the flow velocity was high, the pollutants cannot easily precipitate at the artificial canal. If rainstorm or other factors led to rapid inflow increase into the canal, the nitrogen that had been precipitated and adsorbed at canal bottom and wall would be washed out of the canal, hence resulting in increased effluent TN concentrations.

14.4.2.2 Sewage TP Removal

The main process of phosphorus removal, which has a joint action mechanism, includes particulate adsorption, chemical deposition, microbial assimilation, and algae and aquatic plant absorption. The same with inorganic nitrogen, the inorganic phosphorus in the wastewater was absorbed and assimilated by plants, which could be turned into organic ingredients of the plants or carried out chemical precipitation reaction with soil Al, Fe, and Ca.

TP removal efficiency in farmland sewage was tested from May to October of 2012 in Hongcun village and Zhongzhang River artificial ponds, and the results are presented in Figs. 14.11 and 14.12. The TP removal rate for influent was not stable in Hongcun village and Zhongzhang River artificial ponds; with higher TP concentrations in artificial pond influent, the removal efficiency was better. In June and August, TP concentration was higher in Zhongzhang River artificial pond influent, with an average of 0.072 and 0.155 mg/L, respectively; TP removal rate also reached 40–60 %. Similarly, when the average influent TP concentration rose to the highest of 0.058 mg/L in June for Hongcun village artificial pond, the TP removal rate of the artificial pond increased over 30 %.

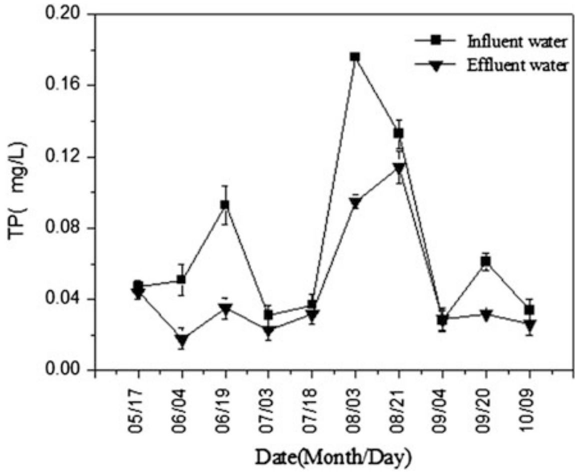


Fig. 14.11 TP change in Zhongzhang River artificial canal

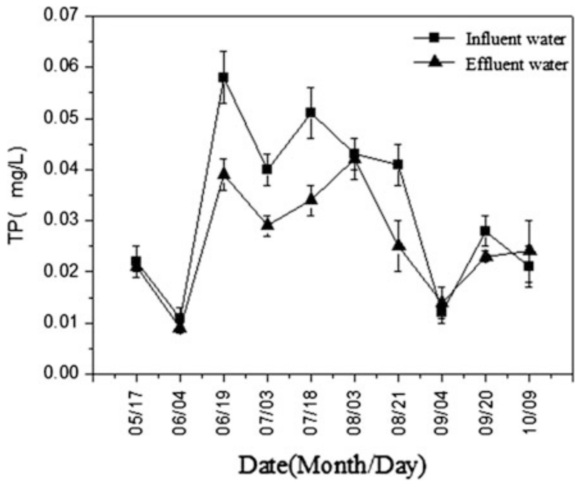


Fig. 14.12 TP removal in Hongcun village artificial pond

However, the TP concentrations in the two artificial pond effluents were higher than those in the influent at some points. This result might be caused by the fact that when the phosphorus in water was lower, some phosphorus that had been adsorbed would be released into water bodies; fish and ducks were also raised and kept in the pond by villagers, which also led to water quality deterioration. In addition, the temperature is an important factor affecting TP removal rate (Zhang and Chen 2005). When temperature increases, algae activity in the pond would be enhanced, and biological assimilation and phosphorus absorption would be much more active.

Similar to Zhongzhang River artificial pond, the TP removal effect of the artificial canal in Zhongzhang River downstream was measured from May to October, and the results are shown in Fig. 14.13. The TP content in Zhongzhang River

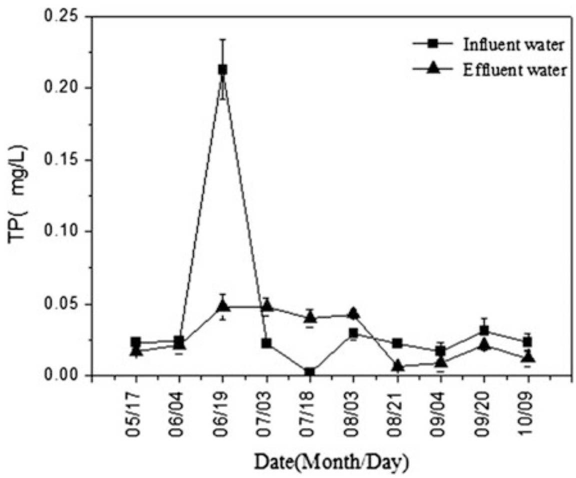


Fig. 14.13 TP removal in Zhongzhang River downstream artificial canal

artificial canal influent increased from the minimum of 0.002–0.203 mg/L; in artificial canal effluent, the TP concentration was relatively stable within the range of 0.006–0.048 mg/L. When the TP concentration of 0.203 mg/L in the influent increased to the highest value, the TP removal rate of the artificial canal reached 77.5 %. The analysis results showed that TP in the artificial canal effluent was higher than that in the influent because TP reached the highest in the early influent; subsequently, the TP concentration sharply declined, and part of the phosphorus that had been absorbed gradually was released into the water. When TP was kept relatively stable in the influent, the TP removal effect of the artificial canal on water quality was stable within the range of 12–47 %. Obviously, the length of the artificial canal was longer than that of artificial ponds. When wastewater flowed in the long process, the sewage suction surface in the canal was much higher than that in the artificial ponds, and phosphorus was much reduced, specifically for wastewater with high phosphorus concentration. Thus, the artificial canal effluent TP could be maintained at a lower level.

14.4.3 Water Pollutant Purification in Artificial Wetland

The effect of TN removal on water quality of the artificial wetland in Hongcun village Shenxi river downstream was monitored from May to October, and the results are shown in Table 14.1. The TN removal rate through plants purifying bed was significantly influenced by water quality and TN concentration, i.e., TN concentration in the influent was higher, and the removal rate was generally higher. From July to early August, the TN purification effect for water quality of the wetland system was better, and TN removal rate for sewage by wetland plants reached about 50 %. In the other months, TN concentrations had a slight difference between the influent and effluent water. In the structure viewpoint, surface flow of artificial and natural wetlands was similar, and wastewater flowed through the wetland surface. This flow is characterized with low investment, simple operation, and low running cost (Wu and Ding 2006). Generally, the conversion pathways of nitrogen in artificial wetland include soil adsorption and ion exchange, aquatic plant absorption, microbial nitrification, denitrification, and ammonia volatilization (Braskerud 2002; Lu et al. 2006). The activity of nitrifying and denitrifying bacteria and plant growth are affected by temperature; thus, TN removal efficiency showed seasonal regularity; in July and August, plants and microorganisms were growing vigorously, and pollutant removal effect was obvious in this season.

Similarly, the effect of TP removal on the water quality of artificial wetland in Hongcun village and Shenxi River downstream was determined, and the results are shown Table 14.1. The change in TP concentration in the water was not very

Table 14.1 Purification effect of TN and TP on Hongcun village downstream artificial wetland

Date (month-day)	TN (mg/L)			TP (mg/L)		
	Inflow water	Effluent water	Removal rate (%)	Inflow water	Effluent water	Removal rate (%)
05-17	16.622 ± 1.413	1.981 ± 0.177	88.10 ± 6.33	1.986 ± 0.016	0.039 ± 0.003	98.10 ± 7.02
06-04	5.441 ± 0.453	1.351 ± 0.201	75.20 ± 5.23	0.103 ± 0.027	0.010 ± 0.001	90.80 ± 6.65
06-19	2.367 ± 0.356	0.971 ± 0.505	59.00 ± 4.01	0.114 ± 0.024	0.084 ± 0.013	26.30 ± 2.35
07-03	33.317 ± 0.034	1.318 ± 0.346	96.00 ± 7.52	0.198 ± 0.012	0.068 ± 0.0.006	65.90 ± 5.56
07-18	5.590 ± 0.193	1.774 ± 0.141	68.30 ± 3.95	0.083 ± 0.012	0.011 ± 0.001	86.70 ± 6.33
08-03	6.613 ± 0.118	2.210 ± 0.314	66.60 ± 3.63	0.127 ± 0.002	0.029 ± 0.002	77.60 ± 4.25
08-21	5.393 ± 0.227	5.400 ± 0.496	−0.10 ± 0.00	0.078 ± 0.031	0.061 ± 0.005	21.80 ± 1.63
09-04	5.183 ± 0.369	3.640 ± 0.207	29.80 ± 2.13	0.154 ± 0.019	0.010 ± 0.001	93.50 ± 7.13
09-20	5.102 ± 0.305	3.614 ± 0.422	29.20 ± 2.05	0.027 ± 0.004	0.016 ± 0.002	42.60 ± 2.88
10-09	4.578 ± 0.059	3.432 ± 0.008	25.00 ± 1.63	0.035 ± 0.009	0.019 ± 0.002	47.10 ± 2.68

obvious, i.e., no regularity was observed, and the phosphorus removal of the wetland system was below the expectation. In the wetland system, the changes in phosphorus content depended mainly upon the joint action in the substrate surface of adsorption and phosphate release, biological assimilation, and rotting and releasing processes (Song et al. 2005). In surface flow of artificial wetland system, phosphorus removal mechanism is multiple, which was a combination of various factors, such as, sewage chemical reaction among phosphorus and aluminum, iron, and calcium ions; and adsorption by ditch wall and ditch sediments (Zhang et al. 2004). In the preceding section of the system, the TP concentration decreased rapidly, which may be due to the adsorption effect of matrix on it. In addition, for the matrix effect, Ji et al. (2002) found that when the TP concentrations in the wastewater are low, the artificial wetland not only removes phosphorus from wastewater, but also increases the phosphorus concentration in wetland effluent, and the increased phosphorus is mainly from the release of wetland matrix.

In August, the COD removal efficiency was higher in the wetland system, which was in accordant with the period of plant growing vigorously (Table 14.2). This result showed that plants in wetland played an important role on phosphorus removal. When air temperature decreased, various biological activities were weakened, which led to the uptake of phosphorus reduction; furthermore, the sediments in the pool could precipitate phosphate through anaerobic degradation. Another important reason was that heavy rains caused a sharp increase in water entering the wetland, and part of the sewage without purification timely outflowed from the wetland. Some villagers in wetland were also herding cows and raising ducks, and these human activities also led to water quality deterioration.

Table 14.2 Removal efficiency of COD at Hongcun village downstream artificial wetland

Date (month-day)	COD (mg/L)		
	Inflow water	Effluent water	Removal rate (%)
05-17	121.570 ± 8.451	21.460 ± 1.265	82.30 ± 5.66
06-04	47.248 ± 2.301	21.080 ± 1.352	55.40 ± 2.94
06-19	64.312 ± 2.563	34.860 ± 2.103	45.80 ± 2.38
07-03	99.367 ± 3.120	32.840 ± 1.985	67.00 ± 4.85
07-18	33.597 ± 1.568	17.790 ± 1.110	47.00 ± 2.33
08-03	37.450 ± 2.452	14.740 ± 0.850	60.60 ± 3.61
08-21	21.076 ± 1.103	21.010 ± 1.233	0.30 ± 0.01
09-04	46.330 ± 2.265	22.480 ± 1.252	51.50 ± 3.14
09-20	24.701 ± 1.263	23.110 ± 1.356	6.40 ± 0.41
10-09	19.807 ± 1.142	16.020 ± 0.988	14.80 ± 1.05

14.5 Discussion and Conclusions

Artificial pond–wetland combined system takes advantage of pond and artificial wetland systems to optimize the combination. Hence, both can play the roles of its own technology, but also achieve the complementary; this combined system improves the effect on TN, TP, and organic matter removal and can effectively reduce wetland clogging and prolong the life of the wetlands. Artificial pond and canal–wetland is a complex of storm detention ponds, infiltration trenches, and small pre-dams, which has the function on pollution reduction, pollutant interception, erosion protection, water purification, and water recharge (see Fig. 14.14). These functions have been proven via testing.

(1) Artificial ponds and canals for sewage TN and TP had rather high removal efficiency, which had a close relationship to the influent concentrations of TN and TP. When the influent TN concentration was higher than 5 mg/L, the TN removal rate in the artificial pond and canal reached 63.4 and 48.1 %, respectively; in June, the TP concentration of sewage flowing into the pond and canal was higher, the TP removal rate of the artificial pond increased to 60 %, and the TP removal efficiency of artificial canal was better than that of the artificial pond, reaching 77.5 %. A significant relationship was observed between the removal efficiency of downstream wetland and seasonal changes, i.e., during the season when plants were growing vigorously, the removal rate

Fig. 14.14 Artificial pond–wetland combined system in Anji (Photograph taken by Jianfeng Zhang)

was high for water with higher TN concentration. This observation also showed that artificial pond, canal–wetland combined system was an effective way to prevent NPS pollution and implement water ecological restoration.

(2) With several years of operation, the effect of artificial pond–wetland combined system on NPS pollution control in Shenxi River watershed had been achieved. In 2011–2013, the pond–wetland combined system in Hongcun village and Shenxi River downstream was in trial operation; during the adjustment period, the TN concentration in water flowing into the system was high, with an average of 2.8 mg/L, and the highest value was 5.6 mg/L; TP was 0.14 mg/L averagely, and the highest value increased to 0.45 mg/L; both exceeded Class V water environmental quality standards prescribed by the State. In this case, the effect of TN and TP removal of the pond–wetland combined system on farmland sewage with high concentrations of nitrogen and phosphorus occurred initially. Apparently, the annual average TN removal rate reached 60.4 %, and the highest value increased to 86.8 %; meanwhile, the average TP removal rate was 78.6 %, and the highest value was 94.9 %. Monitoring the effluent of the system, the results showed that wetland effluent TN was 1.11 mg/L averagely; TP averagely obtained 0.03 mg/L, which basically approached the Class III water environmental quality standards.

(3) For sewage with higher concentrations of TN and TP in the artificial pond–canal system as the first step of NPS pollution control, the amount of nitrogen and phosphorus in water could be significantly reduced. However, when the nitrogen and phosphorus concentration in influent water declined sharply, the canal system would release the part of nitrogen and phosphorus into the water, which had been precipitated and adsorbed in the artificial pond. This observation was also determined by the structural characteristics of the artificial pond–canal system, i.e., artificial pond–canal system could only accommodate the limited volume of pollutants, and it was easily filled. Therefore, to replace the matrix or clean the sediments of artificial pond–canal system regularly was necessary to ensure the effect of N and P reduction, and the more stable system.

(4) Furthermore, during the process of project implementation, individual villagers were herding cows and raising ducks in the system, which brought the destruction of wetland plants and interference in the sampling analysis. Thus, to better control the NPS pollution, not only scientific planning and design are required as a support, but also a combination of internal socioecosystem dynamic mechanism in the watershed. In addition to the support of local people and cooperation, all of us jointly safeguarded the system, combined with the application of ecological interception technology to achieve optimal ecological restoration.

References

Braskerud BC (2002) Factors affecting phosphorus retention in small constructed wetlands treating agricultural non-point source pollution. Ecol Eng 19(1):41–61

Chai SW, Pei XM, Zhang YL et al (2006) Research on agricultural diffuse pollution and controlling technology. J Soil Water Conserv 20(6):192–195

Chen JQ (1996) Riparian vegetation characteristics and their functions in ecosystems and landscapes. Chin J Appl Ecol 7(4):439–448

Chen QW, Ouyang ZY (2005) Watershed ecology and modeling system. Acta Ecologica Sinica 25(5):1184–1192

Chun T, Gao M, Xu C et al (2010) Research status and prospect on influential factors and control technology of agricultural non-point source pollution: a review. Soils 42(3):336–343

Coveney MF, Stites DL, Lowe EF et al (2002) Nutrient removal from eutrophic lake water by wetland filtration. Ecol Eng 19(2):141–159

Cui LH, Lou Q, Zhou XH et al (2009) Purification efficiency of wastewater in Dongguan canal by different hybrid constructed wetlands. Ecol Environ Sci 18(5):1688–1692

Hammer DA (1992) Designing constructed wetlands systems to treat agricultural nonpoint source pollution. Ecol Eng 1(1):49–82

Ji GD, Sun TH, Li S (2002) Constructed wetland and its application for industrial wastewater treatment. Chin J Appl Ecol 13(2):224–228

Li ZH, Zhang YG, Ren TZ (2008) The loads and control suggestions of agricultural non-point nitrogen and phosphorus pollution in Taihu basin. Chin Agric Sci Bull 24:24–29

Liu WX (1997) Study on the application of artificial wetland in agriculture non-point source pollution. Res Environ Sci 10(4):15–19

Liu GY (2009) The study of controlling agricultural non-point source pollution with pond–wetland system in Shenxi watershed. Southwest Univ, Chongqing

Liu H, Dai ML, Liu XY et al (2004a) Performance of treatment wetland systems for surface water quality improvement. Environ Sci 25(4):65–69

Liu W, Cui LH, Zhu XZ et al (2004b) Purification efficiency of wastewater by constructed wetland treatment systems based on the combination of horizontal-flow and vertical-flow. J Agro-Environ Sci 23(3):604–606

Lu SY, Jin XC, Yu G (2006) Nitrogen removal mechanism of constructed wetland. Acta Ecologica Sinica 26(8):2670–2677

Shan BQ, Chen QF, Yin CQ (2006) On-line control of stormwater pollution by pond-wetlands composite system in urban tourist area. Acta Sci Circumst 26(7):1068–1075

Song ZW, Wang RQ, Xi JX et al (2005) Nitrogen and phosphorous removal efficiency and dynamic feature of constructed wetlands for sewage treatment. Chin J Ecol 24(6):648–651

Wang XH, Yin CQ, Shan BQ (2005) Control of runoff and retention of diffuse P-pollutants by sink landscape structures of agricultural watershed. Acta Sci Circumst 25(3):293–299

Wang M, Ye M, Yin W et al (2008) Preliminary study on multi-ponds and artificial wetland system in urban non-point pollution control. Yangtze River 23(39):91–94

Wei FS, Bi T, Qi WQ et al (2002) Water and wastewater detection methods, 4th edn, pp 32–47, 210–255

Wen J, Luo DQ, Luo XH et al (2004) Agriculture non-point source pollution and control measures of Qiandao Lake Area. J Soil Water Conserv 18(3):126–129

Wu JQ, Ding L (2006) Study on treatment of polluted river water using pilot-scale flow constructed wetlands system. Environ Pollut Control 28(6):432–434

Yang CG, Gu GQ, Li JH et al (2008) Residence time distributions and variation of N, P in the subsurface-flow constructed wetlands for purification of eutrophic aquaculture water. Environ Sci 29(11):3043–3048

Yin CQ, Mao ZQ (2002) Non-point pollution control for rural areas of China with ecological engineering technologies. Chin J Appl Ecol 13(2):229–232

Yu ZM, Yuan XY, Shi WM (2010) The technology of constructed wetlands to non-point source pollution water treatment. Chin Agric Sci Bull 26(3):264–268

Zhang TP, Chen WL (2005) Advances in removal efficiency of nitrogen and phosphorus in constructed wetland ecosystem. Ecol Environ 14(4):580–584

Zhang J, Zhou Q, He R (2004) Mechanism of nitrogen and phosphorus removal in free-water surface constructed wetland. Ecol Environ 13(1):98–101

Zhang W, Fang MY, Zhang JF et al (2011) Study on agricultural non-point source pollution control by pond-wetland combined system. For Res 24(1):116–122

Zhao YH, Deng XZ, Zhan JY et al (2010) Study on current situation and controlling technologies of agricultural non-point source pollution in China. J Anhui Agric Sci 38(5):2548–2552

Chapter 15
N and P Absorption by Hydrophytes and Wetland Sustainable Management

Abstract The function of wetlands on non-point source pollution is clear; thus to conduct wetland sustainable management is significant. As typical wetland plants, the removal effect and height distribution of N and P of reed, cattail, and giant reed were determined in Yixing. Results showed that all these plants could reduce N and P concentrations in wetlands, and a “backflow” rule of nitrogen and phosphorus was observed in the plants. In spring and summer, the nitrogen and phosphorus contents were high, but these nitrogen and phosphorus returned to the lower part of the plants during autumn and winter. Therefore, this rule is important in wetland management, specifically for determining plant harvesting time. This study presents the wetland restoration and sustainable management mode, which not only can protect farmers’ interests but also help promote wetland restoration work steady and orderly forward. Hence, the principle of “positive publicity, financial compensation, community participation, technology support, market leading, model advancing, and common management” can be used as guidelines of wetland restoration work for large-scale wetland restoration and construction in the overall Taihu Lake watershed.

Keywords Wetland restoration · Hydrophyte · Wetland management · Artificial wetland · Nutrient removal · Distribution · Nitrogen and phosphorus · Community participation · Water quality · Management mode · Reed · Cattail · Giant reed

Artificial wetland water purification technology has been widely applied (Jiang and Gui 2002). Generally, its principle is after the sewage flows in the purification pool: First, it contacts with the plants, and larger particle pollutants in wastewater are intercepted by the roots and stems of plants and substrate surface, thereby forming sediments (Jiao et al. 2003). The nutrients in wastewater can be absorbed by plants, and with these plants growing and harvesting, nutrients will be decreased. The sewage can also be purified through aerobic and anaerobic bacteria, and it eventually becomes clean water (Hay et al. 2006; Bedard et al. 2005; Barling and Moore 1994).

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This observation is caused by many characteristics, such as low investment and easy operation, thus given more attention. With societal development, many of the earth's natural wetlands have been severely disrupted, which causes environmental hazards. Artificial wetland purification technology should purify water quality and improve environment (Henderson et al. 1998; Jon et al. 2005).

15.1 Introduction

Problems, such as lacking public wetland protection consciousness and ecological compensation policy, narrow wetland plant utilization market, imperfect management mode, and wetland plant harvesting methods, are still existing in Taihu Lake wetland ecosystem management (Yang et al. 2013). Therefore, research on the characteristics of N and P absorption by wetland plants and sustainable management mode of wetland ecosystem was carried out. Two aspects of sustainable management model were proposed. One model is sustainable management, namely in the form of returning lands to households. The lands were formerly managed by individual households for agriculture; since the water crisis affair occurring in 2007, these lands are rented by the community or company to plant trees or transform wetlands, i.e., land use is given priority to ecological function. The organization form is as follows: company (investor) + base (land owner) + contract households (manager). The significant characteristic of the wetland ecosystem management model is community participation management. The other model is the ecologically sustainable plant harvest and management model; according to the laws of nitrogen and phosphorus absorption and transportation by wetland plants, the wetland system is established based on nutrient cycle. Wetland ecological restoration compensation scheme has also been proposed, including public finance and market mechanism, i.e., the local government and farmers signed land lease contracts to provide seed, coordinate with acquiring companies signing the agreement on products and purchasing at an ensured price, give farmers the necessary ecological compensation; and the contract farmers plant, maintain, harvest, and sell crops in accordance with the requirements stipulated in the contract.

15.2 N and P Absorption and Cycle in Wetland Ecosystem

According to the transport law of nitrogen and phosphorus absorption by the wetland plants, the wetland system nutrient recycling and harvest management model are initiated and practiced to promote the realization of wetland ecologically sustainable management.

15.2.1 Seasonal Change of N and P in Various Organs of Reeds

Generally, the characteristics of nitrogen and phosphorus accumulation are in the subsurface and upper stems of the wetland plants in Taihu Lake (Wang et al. 2007; Phillips 1993). The nitrogen and phosphorus contents in the root and stem of reed (*Phragmites australis* (Cav.) Trin. ex Steud) were changing seasonally, and the contents in the reed rhizome reached the largest in December 2009; the values of nitrogen and phosphorus were 10.09 and 1.01 g/kg, respectively. The nitrogen and phosphorus contents at the stem were lowest at 0.20 and 0.10 g/kg, respectively. This result showed that during the late time of growth and development of wetland plants, nitrogen and phosphorus were transported from the stem to the root. Obviously, if harvesting the reed in December is not conducive to remove nitrogen and phosphorus from the environment, it should be harvested before December.

For one growth period of reed, a single content peak of nitrogen and phosphorus was observed in the upper part, and the highest accumulation of nitrogen and phosphorus occurred at the end of October. The appropriate harvesting time should be at the end of October. Figure 15.1 shows that the nitrogen and phosphorus contents in the stem were relatively higher in September, but the reed was still in the growth period; during this period, the fiber quality of stalks was unfit for paper-making and weaving, therefore not suitable for reed harvesting. The growth period of reed was between March and December in 1 year, and the current harvest period of reed was in early March (before the new growing season begins). To realize the objective of environment purification by reeds, the current harvest time should be adjusted appropriately. Figure 15.1 presents that the results in 2009 and 2010 had an obvious difference in nitrogen and phosphorus contents, which might be related to the accumulation of nitrogen and phosphorus in perennial wetland plants.

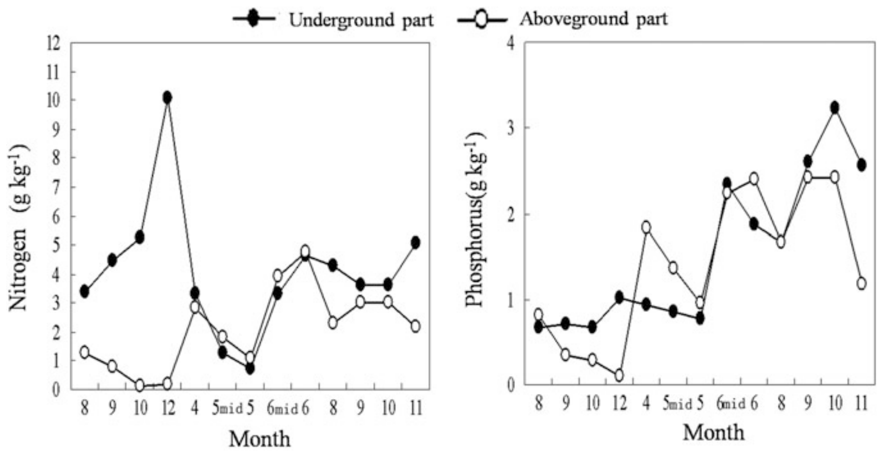

Fig. 15.1 Seasonal changes in N and P accumulation in different parts of wetland plants

As shown in Fig. 15.2, differences in phosphorus content between the root and stem of reeds in wetlands were quite obvious; in October 2009, the phosphorus contents of the underground part and stem were 0.66 and 0.29 g/kg (dry matter), respectively; at the same period in 2010, the phosphorus contents of the underground part and stem were 3.23 and 2.41 g/kg, respectively; these values for underground part and stem increased 3.87 and 7.45 times on the average compared with those in 2009 (Fig. 15.2).

In the growing season of August 2010 and August 2009, the average increase in the phosphorus amount in the underground and stem was 1.5 and 1.0 times, respectively. This result may be due to perennial reeds have a certain “accumulation effect” on phosphorus in underground part; hence, the new organization can rapidly obtain nutrition for growth next year, which enables the increase in the phosphorus content of the stem every year to sustain plant growth.

However, the accumulation characteristics of nitrogen in the stem were more obvious than those in the root for annual nitrogen difference. Nitrogen accumulation in August, September, and October of 2010 increased by 0.85, 2.89, and 21.29 times compared with those in 2009. This annual increase in nitrogen for the underground part was not obvious, except during the growing period in August; the absence of increase may be related to the present forms of nitrogen and transformation in the underground part (Mitsch 1994; Mather 1969).

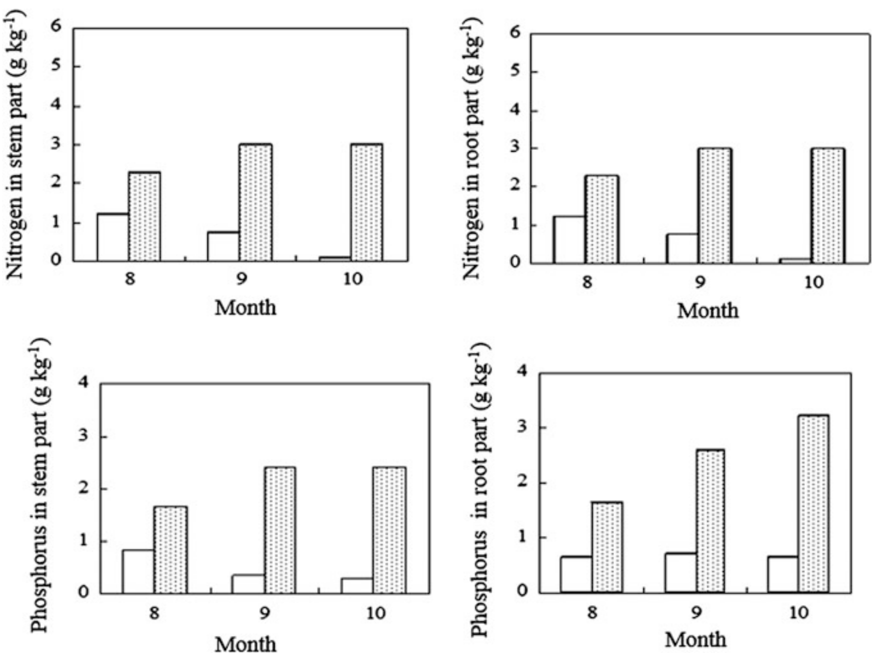

Fig. 15.2 Inter-annual variability of N and P contents in the root and stem of reeds

15.2.2 Spatial Distribution Characteristics of N and P in Reeds

In different parts of wetland plants, not only significant seasonal difference of nutrient accumulation can be observed, but the nutrients would also perform "backflow," i.e., from the upper part, the nutrients transferred to the underground part during the senescence period of the plants; consequently, the phosphorus content in underground part was higher than the aboveground part when plants went into later growth stage. Therefore, harvesting these wetland plants would increase the amount of phosphorus removal and avoid nutrient loss before the senescence period. Figure 15.3 presents the height distribution of nitrogen and phosphorus contents of the reed in Taihu Lake during growing season and later growth period; the nitrogen and phosphorus contents in the underground part of the reed were 4.29 and 1.66 g/kg in August, respectively; in November, the underground part content of nitrogen and phosphorus reached 5.08 and 2.56 g/kg, respectively; these values were clearly higher than those in August. However, the average content of nitrogen and phosphorus on aboveground in August was higher than that in November, which indicated that the nitrogen and phosphorus of reeds had a "backflow" from the upper part to the lower part, even to soil environment.

As shown in Fig. 15.3, the average content of nitrogen and phosphorus for different height and organs of the reed gradually increased from top to bottom at the same period. Nevertheless, for the stem, the difference in height distribution of nitrogen and phosphorus contents for the two months (in August and November) was not obvious. In November, the height distribution trend of phosphorus, which increased gradually from top to bottom, was obvious; but for the stem, the difference of height distribution was not apparent in August and November. Generally, the height distribution of phosphorus was obvious in November and gradually increased in top-down manner; however, the distribution showed a top-down gradual decrease in August, and regularity was not obvious.

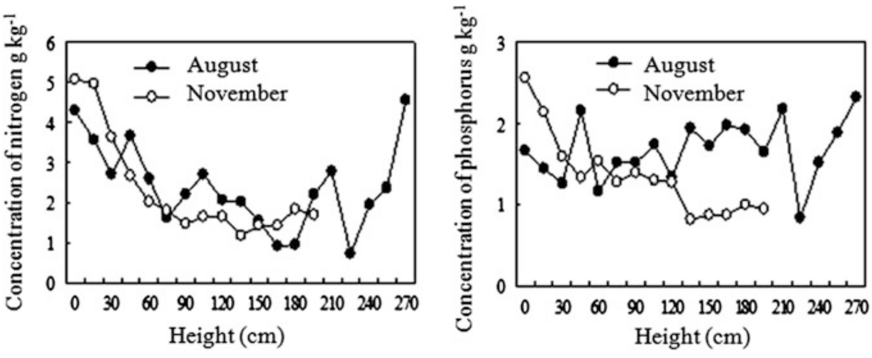

Fig. 15.3 Height distribution characteristics of nitrogen and phosphorus contents in reeds during growing season (August) and later growth stage (November)

15.2.3 Seasonal Accumulation of N and P in Different Organs of Cattail

Figure 15.4 shows the seasonal variation of nitrogen and phosphorus accumulation in the aboveground and underground parts of cattail (*Typha orientalis*). The accumulation per unit weight of cattail gradually increased during August to November, and a similar increasing trend began from next April to August, which was the period of development and growth for cattail; subsequently, it gradually decreased with the arrival of senescence phase.

The phosphorus accumulation in aboveground part presented a similar seasonal change regularity, which implied that the characteristics for nitrogen and phosphorus transportation and accumulation were upward and then reflux with annual seasonal change.

From the histogram, the characteristics of nitrogen and phosphorus accumulation per unit weight in the underground part of cattail with seasonal change can be observed. Clearly, in August, the accumulation reached the highest for above- and underground parts; however, with the growth period extending, the nitrogen and phosphorus contents in underground part decreased, and the reducing rate was less than that in aboveground part.

Nutrient transfer (reflux) is one of the most important strategies for maintaining plant nutrition; this strategy has vital effect on competition, nutrient absorption, and

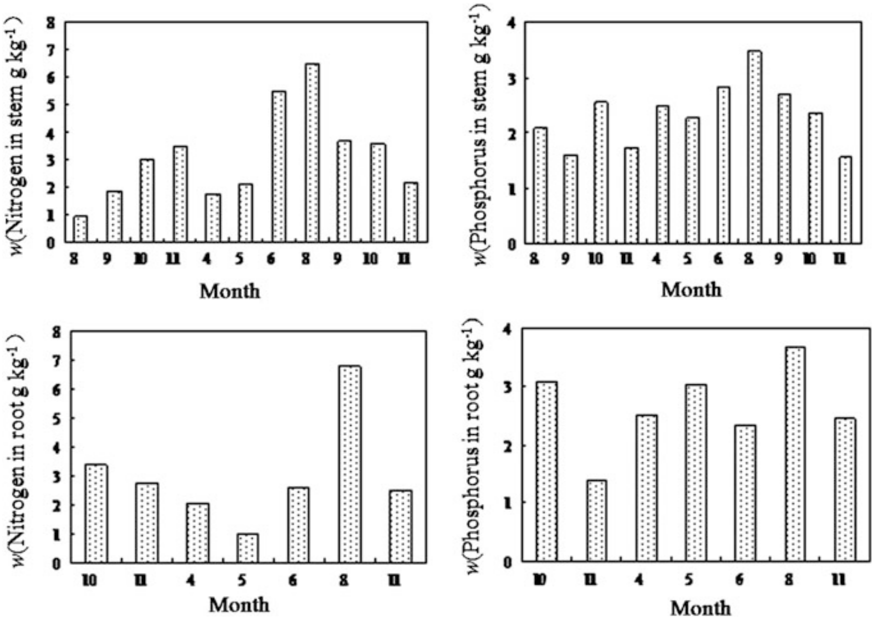

Fig. 15.4 Accumulation of N and P in cattail in different seasons (2009–2010)

productivity. For example, some trees have a particular nutrient accumulation and storage period; for leaves, nutrient content is high during the early stage of the growth process and subsequently decreased during the maturity period; leaf nutrients go back to branches and roots, which is important for perennials.

Cattail is a perennial plant in Taihu Lake watershed, which has an important ecological significance in purifying and improving water quality. According to the results analyzed above, nutrients, such as nitrogen and phosphorus, can “backflow” to the underground part, and this period is defined. Therefore, separate harvesting of the aboveground and underground parts helps ensure the cattail reproduction ability; this harvesting also brings a large number of nitrogen and phosphorus to achieve the maximum effect of water purification. Related studies showed that cattails could absorb nitrogen and phosphorus at about 2630 and 403 kg per hectare annually. Furthermore, a number of studies also proved that under the certain hydraulic retention time, cattail has good performance to remove the pollutant of COD, ammonia nitrogen, total nitrogen, and total phosphorus (Magette et al. 1989; Ma et al. 1997); thus, it is suitable plant for wetland restoration in Taihu Lake watershed.

15.2.4 Spatial Distribution Characteristics of N and P in Cattail

Nutrient accumulation in different parts of wetland plants not only has significant seasonal change and inter-annual difference; at the late stage of plant growth or senescence phase, the nutrients also transfer from stems and leaves and “backflow” to the underground parts or soil environment, thereby resulting in higher nitrogen and phosphorus contents in the underground part of the plant than those of aboveground part. Therefore, according to the nutrient element accumulation threshold of wetland plants, before the senescence phase, reasonable harvest time should be selected; appropriate harvest time is significant for wetland plants to better play water purification functions in lakeside zones and carry much more nitrogen and phosphorus from the environment. Figure 15.5 shows the height distribution of nitrogen and phosphorus contents for cattail during the growing season in June and later growth stage in November 2010. The distribution of nitrogen and phosphorus in plants not only reflects the different storage capacity of the different parts of wetland plants, but also reflects the transport law of nutrient elements. As shown in Fig. 15.5, the overall trend of nitrogen and phosphorus content change in early growing period June was from the underground part to the upper part and increased gradually with cattail growth; this period was the early stage of growth for cattail meristem development; thus, the organs were growing fast, and the demand on nutrition was large; moreover, much more nutrients should be transported to the upper part from the ground, which will help the stems and leaves to grow and develop rapidly (Fig. 15.5). However, in the late growth period

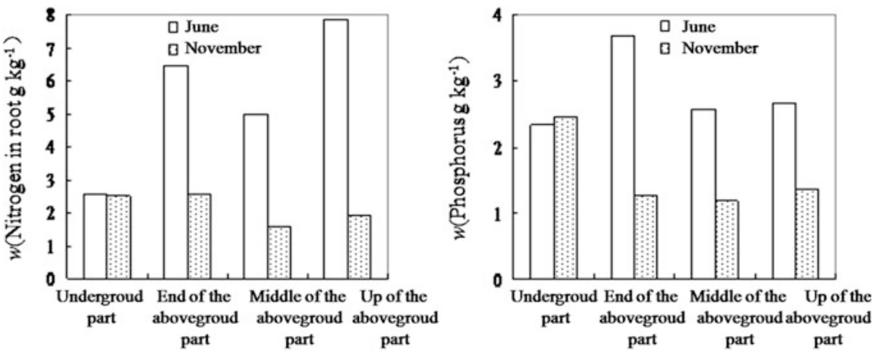

Fig. 15.5 Height distribution of nitrogen and phosphorus contents in cattail at different growth phases

of November, from the perspective of the whole plant, nitrogen and phosphorus contents in roots were higher than those in the aboveground part; the content presented the trend of bottom-up gradual reduction, i.e., nutrients, such as nitrogen and phosphorus in the stems and leaves, began to transport to the underground part. In addition, Fig. 15.5 shows that the overall level of nitrogen and phosphorus in November was lower than in June, which may be due to the fact that most of the nutrients were not only transported to the lower part gradually, but even to the soil environment (Qian et al. 2002; Yu et al. 2003).

15.2.5 Absorption and Accumulation of N and P in Arundo donax

Based on in vivo tracking and monitoring of nitrogen and phosphorus in giant reed (*A. donax*), the nitrogen and phosphorus contents of giant reed had a seasonal change pattern (Fig. 15.6). In the same growth stage, nitrogen and phosphorus contents gradually increased in the stem of *A. donax* with plant growth and development; nevertheless, at the later growth stage, plant nitrogen and phosphorus would transport to the lower organizations or to soil environment. Comparing the inter-annual accumulation of giant reed, an inter-annual characteristic of nitrogen and phosphorus accumulation was observed. Compared the accumulation in 2010 with that in 2009, the increase was apparent, but in the late growth phase, the cumulative effect was abated. Obviously, the cumulative effect can promote root development and help plants effectively absorb nutrient elements from soil environment.

Similar to reed, giant reed also presented height distribution features of nitrogen and phosphorus. The nitrogen and phosphorus contents in November were compared with those in August. During late growth period (in November), the nitrogen and phosphorus contents of *A. donax* in the roots were significantly higher than

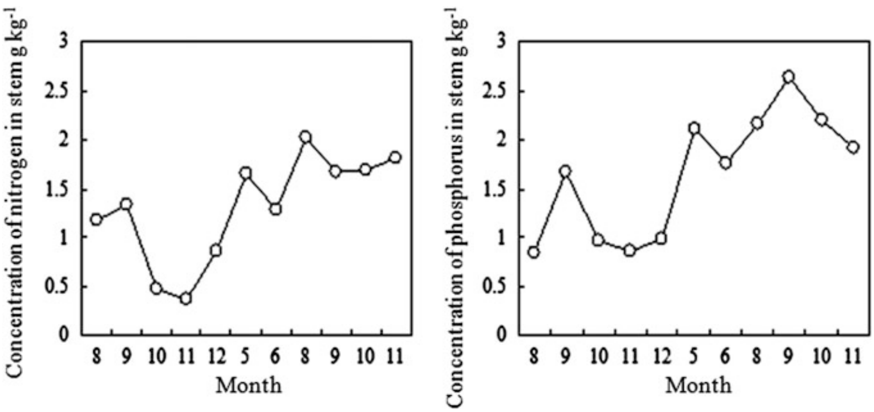

Fig. 15.6 Accumulation changes of N and P in giant reed stem at different seasons

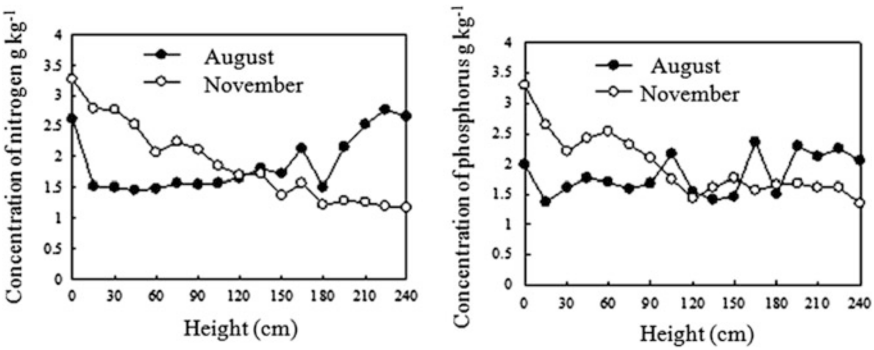

Fig. 15.7 Characteristics of the height distribution of N and P contents in *Arundo donax* at different growth period (2008)

those in the aboveground part during the late growth period (November). The nitrogen and phosphorus contents from bottom to top gradually were reduced (Fig. 15.7). However, in August, the height distribution exhibited an opposite trend. At the same height, the nitrogen and phosphorus contents showed obvious difference in the two growth periods.

15.3 Wetland Sustainable Management

The function of wetlands on non-point source pollution is clear; thus to conduct wetland sustainable management is significant (Yu et al. 2002; Yang et al. 2001). Based on the home visits and a number of villager's consultative forums, the wetland management policy is proposed with full respect to the requests of the local farmers and government; clearly, the policy emphasizes that the existing land ownership does not change. The background of the policy "returning to rent land by villagers" is that formerly the lands were managed by individual households for agriculture; since the water crisis affair occurring in 2007, these lands are rented by the community or company to plant trees or transform wetlands, including forested wetlands, i.e., land use is given priority to ecological function. To better manage these ecological lands and cause them to play more significant roles, the lands are leased to villagers, namely "returning to rent land by villagers." Taking the form of "returning to rent land by villagers," that is, the local governments sign land lease contracts with the farmers, provide seedlings, coordinate the relative firms to sign agreements for product purchase in the ensured protective price, and give the necessary ecological compensation; farmers undertake planting, maintenance, harvesting, and selling of the contracted corresponding crops. The current practice of the policy has proven that it is easily accepted by local farmers, and the multiple effects have been gained, such as the consciousness on environmental protection is becoming popular, and the incentive of wetlands management is motivated.

15.3.1 Ecological Compensation from Public Finance

To ensure that farmers' income is not affected during the process of wetlands management, the two compensation methods of cash and materials were determined, and artificial forest types and planting ways were further clarified after consulting with the village cadres and villagers. In terms of the ecological functions and economic benefits, the deciduous tree species or varieties for local water conservation plantations are as follows: *Ginkgo*, *Camptotheca acuminata* Decne, *Pterocarya stenoptera*, *Ulmus pumila*, *Ailanthus altissima*, *Pistacia chinensis* Bunge, *Melia azedarach*, *Koelreuteria paniculata*, *Sophora japonica*, *Firmiana simplex*, *Sapium sebiferum*, *Metasequoia glyptostroboides*, *Taxodium ascendens*, *Taxodium distichum*, *Catalpabungei*, *Aesculus chinensis*, and *Albizzia julibrissn*; the evergreen tree species mainly include *Ilex chinensis*, *Elaeocarpus decipiens*, *Ligustrum lucidum*, *Taxus chinensis*, *Osmanthus fragrans*, *Viburnum odoratissimum*, *Michelia figo*, and *Schima superba.* Mixed forests are advocated; the proportion for evergreen tree species/deciduous tree species is 3/7, and that of coniferous forest and broad-leaved forest is 3/7. Moreover, in the stands that upper arbors account for over 70 %, chemical fertilizers are not allowed. In the areas within 200 m from offshore and for fishing, hydrophytes, such as reed, wild water chestnut, lotus, cattail, *Echinochloa crusgalli*, *Euryale ferox*, *Zizania latifolia*, and sedges are widely cultivated to restore the original appearance of the wetland and ecological functions. In the areas offshore within 15 km, in addition to the upstream of the rivers connected with the lake, all riparian side (revetment outsides) reeds and other aquatic plants were established (see Figs. 15.8, 15.9, 15.10 and 15.11).

Fig. 15.8 Forest wetland in Yixing (photograph taken by Jianfeng Zhang)

Fig. 15.9 Wetland landscape in Yixing (photograph taken by Jianfeng Zhang)

Fig. 15.10 Wetland with aquatic plants in Yixing (photograph taken by Jianfeng Zhang)

Fig. 15.11 Reed wetland in Yixing (photograph taken by Jianfeng Zhang)

15.3.2 Ecological Compensation Oriented with Market Mechanism

Wetland ecological restoration is not supported fully by the public financial subsidies, which will therefore become a heavy financial burden for local governments. To ensure the sustainability of wetland ecological restoration, the market mechanism must be introduced and implemented, hence changing the mode of purely blood transfusion to blood-making, so as to promote orderly and healthy development of wetland ecological restoration. Thereby, four kinds of wetland tourism marketing modes were initiated, namely wetland tourism management mode, wetland tourism product development mode, wetland tourism environment protection mode, and wetland tourism marketing mode. These four patterns were mutually influencing and interacting one another, thus promoting the sustainable development of tourism industry and unified wetland management. During the procedure, the government is in the lead position, guiding and indirectly participating wetland tourism. Tourists are the main body of wetland tourism activities, and tourism activities should be carried out to improve the environmental quality as a benchmark. Community residents are the participants and supporters of wetland tourism, whose incentive and action directly affect the development of wetland tourism activities. Tourism enterprises are the organizers of wetland tourism.

15.3.3 Management with Community Participation

This mode has been initially established and applied in some wetland restoration projects, such as in Dingshu town, and Dapu and Huangdu channel wetland restoration program.

With successful practice, wetland management mode is a simple operation, with sustainable gain and efficient use, and large-scale application in wetland restoration projects as the innovation of government management system and mode. To date, the management mode is initially established based on land lease, individual contract, integration of agricultural production, and local industrialization chain. In detail, the organization form is the company (investor) + base (land owner) + farmers (manager), by which all interested sides join together and perform community participation management; thus, the community residents can participate in the management plan drafting, implementation, and evaluation, as well as enjoy the wetland resources. Therefore, the joint management model is gradually formed, i.e., wetland management committee and community residents. Figure 15.12 presents different wetland management types. In the common management mode of community participation, the four main bodies are as follows: governments, experts, enterprises, and farmers; they play different roles and have their respective assignments.

For this management mode, the government is responsible for organizing publicity, inspiring wetland protection awareness of local farmers, and providing

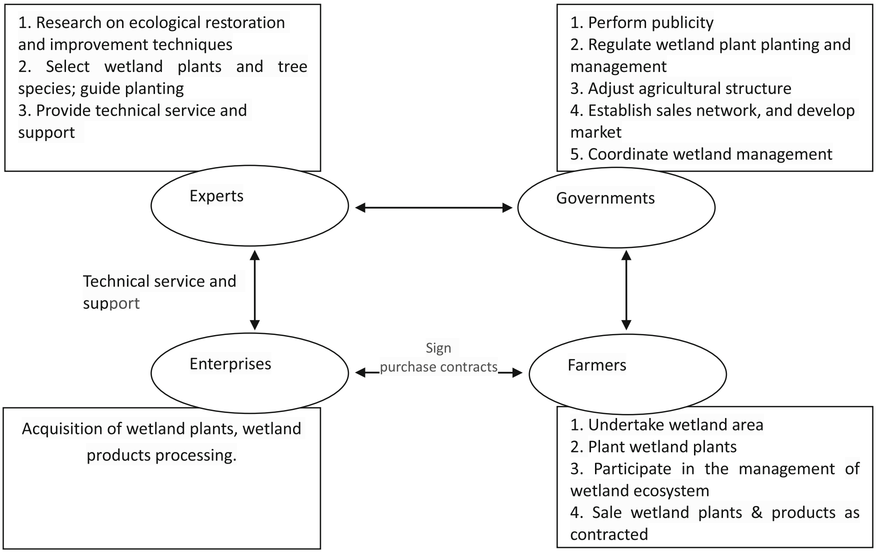

Fig. 15.12 Wetland ecosystem management model together with framework

ecological compensation contracts for farmers. Moreover, the government and concerned departments should provide seeds and seedlings in addition to financial support for planting and maintaining. The governments lead and guide artificial wetland construction by supplying seeds and seedlings. Meanwhile, the government uses different kinds of measures to establish and expand sales market; form the production, transportation, and marketing service mechanism on wetland aquatic plants; and effectively mobilize the enthusiasm of the local farmers to participate in ecological construction. The local government actively guides the enterprises to carry out wetland plant high value-added product processing and exporting, and encourage them to develop various reed products, such as panels, feedstuff, and weaving, thereby adjusting the industrial structure and increasing farmers' income.

During the procedure, the expert group of forested wetland ecological restoration is established; this group is mainly responsible for wetland ecological restoration and comprehensive regulation study, researching on wetland plant selection and seedling planting techniques, conducting wetland plant value development and industrialization utilization probing, and providing other related technical support and services.

Furthermore, community residents are responsible for wetland management, including wetland plant establishment and maintenance, participation in the protection of wetland ecosystems, and ensuring the normal operation of the wetland ecosystem. Certainly, in addition to wetland plant planting and tending, the farmers are responsible for harvesting and selling in accordance with the contract signed with the firms or companies.

Enterprises, as the bridge and value amplifier between farmers and market, are responsible for joint research wetland plants product development and further

Fig. 15.13 Wetland with economic crops (photograph taken by Jianfeng Zhang)

Fig. 15.14 Wetland with flowers (photograph taken by Jianfeng Zhang)

Fig. 15.15 Wetland with multiple functions (photograph taken by Jianfeng Zhang)

processing, providing market demand information, and accomplishing the acquisition of wetland plants and products according to the signed purchase contracts with farmers (see Figs. 15.13, 15.14 and 15.15).

15.4 Conclusions

A "backflow" rule of nitrogen and phosphorus exists in plants. This rule is important in wetland management, specifically for determining plant harvest time. This study presents the wetland restoration and sustainable management mode, which not only can protect farmers' interests but also help promote wetland restoration work steady and orderly forward. Hence, the principle of "positive publicity, financial compensation, community participation, technology support, market leading, model advancing, and common management" can be used as guidelines of wetland restoration work for large-scale wetland restoration and construction in the overall Taihu Lake watershed. The main conclusions of the study are as follows:

(1) Wetland ecosystem common management and community participation management mode has good applicability.

For the common management mode, governments (higher level and local government), experts, enterprises, and farmers are coordinated and promoted one other to achieve the industrial chain of wetland construction, management, product processing, and sales. Fully coordinating the relationship among government, experts, farmers, and enterprises can mobilize the enthusiasm of farmers and create the satisfactory conditions for environmental protection. Farmers can also play the roles of masters, hence forming the joint mechanism among governments, scientific research institutions, and enterprises. Consequently, the industrialization of scientific research results is promoted, and sustainable utilization of wetland resources is achieved.

(2) “Returning to rent lands by villagers” is generally a land use pattern accepted by farmers.

Under the premise of not changing the ownership of lands, the government rented the lands around Taihu Lake and employed farmers to change the land farming system; they shifted intensively managed agricultural production to ecological construction and ensured that the income from the lands was not less than the benefits of planting rice and other crops. Government pays the difference as ecological compensation. Under the situation, the costs of fertilizer, pesticide, and labor inputs, as well as crop management time in fields, are all reduced; a certain level of revenue is also increased; thus, this mode is easily accepted by farmers. In Taihu Lake watershed, the community participation mode of the wetland ecosystem management has played important roles.

(3) Economic compensation system is the key to ensure wetland ecosystem restoration.

After changing the farming system, the income may be temporarily lower than that of planting crops because the initial growth of wetland plants only produces few products; at such period, appropriate ecological compensation is the key to ensure that wetland restoration will continue. Generally, to determine the reasonable amount and duration of the compensation according to the growth of wetland plants is necessary to ensure that farmers’ income are slightly higher than the previous crop planting earnings.

(4) Market promotion guarantees the sustainable development of wetland ecological restoration.

The wetland ecological restoration will change from pure financial transfusion blood to self-making blood by introducing market mechanism, thereby ensuring the sustainability of wetland ecological restoration work. In Taihu Lake area, experts and professionals conducted research focusing on the development and utilization of wetland plants and their products; cattail, reed, and other selected plants were screened, and their economic values and water quality purification effect are probed. Guided by the government and through scientific research institutions and enterprises jointly striving to create technological breakthrough, some specific products made of wetland plants have been developed, such as cellulose extracted from *A. donax*, pentosane, and feed protein extracted from reed leaves. Other uses also bring high added value, e.g., aquaculture, handicraft, and establishment of biogas fermentation. To expand the wetland plant development and use, local governments also actively encourage farmers and local technicians to participate fully in the local hand woven traditional advantages. Supported by technicians and cooperated with the local agricultural product processing enterprises, farmers have learned and mastered the wetland plant handicraft processing technology; some wetland plant weaving crafts form willow and mat grass, and *Scirpus yagara* has been successfully brought into the international market. Therefore, introducing market mechanisms in the process of transport and utilization of wetland plants can reduce the government's administrative intervention and costs, increase farmers' income, and cause the market to play important roles in the construction and management of wetland, as well as harvesting, processing, transportation, marketing, and utilization of wetland plants.

(5) Focusing on nitrogen and phosphorus removal and following the growth law of reed, giant reed, and cattail, the harvesting shall be performed quarterly.

According to the analysis results of nitrogen and phosphorus removal in wetland plants, the seasonal "backflow" of nitrogen and phosphorus in wetland plants was first discovered. In spring and summer, the nitrogen and phosphorus contents are high, and the nitrogen and phosphorus contents return to the lower part of the plants during autumn and winter (Gao 1999; Archer and Marks 1997). Accordingly, the management strategies of wetland plants were proposed to provide a basis for long-term, scientific management of multifunctional Taihu Lake wetland.

References

Archer JR, Marks MJ (1997) Control of nutrient losses to water from agriculture in Europe. Proc Fertilizer Soc 6(5):405–409

Barling RD, Moore ID (1994) Role of buffer strips in management of waterway pollution: a review. Environ Manage 18:543–558

Bedard H, Haughn A, Tate KW, Kessel CV (2005) Using nitrogen-15 to quantify vegetative buffer effectiveness for sequestrating nitrogen in runoff. J Environ Qual 34:1651–1664

Gao C (1999) Environmental management options practiced in Europe to mitigate agricultural nutrient pollution of ground and surface water. Agric Eco-Environ 51(2):50–53

Hay V, Pittroff W, Tooman EE et al (2006) Effectiveness of vegetative filter strips in attenuating nutrient and sediment runoff from irrigated pastures. J Agric Sci 144:349–360

Henderson FM et al (1998) Application of C-CAP protocol land-cover data to nonpoint source water pollution potential spatial model in a coastal environment. Photogram Eng Remote Sens 64(10):1015–1020

Jiang G, Gui G (2002) Effective of wetlands in removed of non-point pollutants from agricultural source. Agro-Environ Prot 21(5):471–473

Jiao F, Qin BQ, Huang WY (2003) Management of water environment in small watershed with Hufu town of Yixing city as example. China Environ Sci 23(2):220–224

Jon ES, Karl WJW, James JZ (2005) Nutrient in agricultural surface runoff by riparian buffer zone in southern Illinois, USA. Agrofor Syst 64:169–180

Ma L, Wang Z, Zhang S et al (1997) Pollution from agricultural non-point sources and its control in river system of Taihu Lake, Jiangsu. Acta Sci Circumst 17(1):39–47

Magette WL, Brinsfield RB, Palmer RE et al (1989) Nutrient and sediment removal by vegetated filter strips. Trans Am Soc Agric Eng 32:663–667

Mather RJ (1969) An evaluation of cannery waste disposal by overland flow spray irrigation. Carles Warren Thornthwaite 22:221–246

Mitsch WJ (1994) The nonpoint source pollution control function of natural and constructed riparian wetlands. In: Mitsch WJ (ed) Global wetlands. Old world and new. Elsevier, Amsterdam, pp 351–361

Phillips JD (1993) An evaluation of the factors determining the effectiveness of water quality. A review of their potential use in UK agriculture. Agric Ecosyst Environ 45:59–77

Qian XH, Xu JM, Si JC et al (2002) Comprehensive survey and evaluation of agricultural nonpoint source pollution in Hang-Jia-Hu water-net plain. J Zhejiang Univ 28(2):147–150

Wang H, Li LJ, Wang FZ et al (2007) Application of artificial wetlands on agricultural non-point source water pollution control. J Agric Environ 26(Supplement):441–446

Yang L, Wu R, Qin B (2001) Preliminary study for potential impacts on the aquatic environment of lake Taihu by acid rain. J Lake Sci 13(2):135–142

Yang LZ, Feng YF, Shi WM et al (2013) Advances on agricultural non-point source pollution researches. Chin J Eco-Agric 21(1):96–101

Yu XX, Yang GS, Liang T (2002) Effects of land use in Xiaotiaoxi catchment on nitrogen losses from runoff. Agro-Environ Prot 21(5):424–427

Yu XX, Yang GS, Ou WX (2003) Impacts of non-point source pollution on the water environment of Xitiaoxi watershed, Upper Taihu Basin. J Lake Sci 15(1):49–55

Plant Directory in Yixing

There are 183 families, 559 genus, and 1242 species of vascular plants in Yixing, of which 159 families, 524 genus, and 1193 species are of spermatophyte, and 21 families, 35 genus, and 49 species are of pteridophyte.

Family	Species
Huperziaceae	*Huperzia serrata* (Thunb. ex Murray) Trev.
Selaginellaceae	*Selaginella moellendorffii* Hieron.
	Selaginella nipponica Franch. et Sav.
Equisetaceae	*Equisetum hyemale* Linn.
	Equisetum ramosissimum Desf.
Botrychiaceae	*Botrychium ternatum* (Thunb.) Sw.
Osmundaceae	*Osmunda japonica* Thunb.
Lygodiaceae	*Lygodium japonicum* (Thunb.) Sw.
Gleicheniaceae	*Dicranopteris dichotoma* (Thunb.) Bernh.
Dennstaedtiaceae	*Dennstaedtia pilosella* (Hook.) Ching
Lindsaeaceae	*Stenoloma chusanum* Ching
Pteridaceae	*Pteris dispar* kze
	Pteris multifida Poir.
Pteridiaceae	*Pteridium aquilinum* (Linn.) Kuhn var. latiusculum (Desv.) Underw. ex Heller
Sinopteridaceae	*Cheilosoria chusana* (Hook.) Ching et Shing
	Aleuritopteris argentea (Gmél.) Fée
Hemionitidaceae	*Coniogramme japonica* (Thunb.) Diels
Parkeriaceae	*Ceratopteris thalictroides* (L.) Brongn.
Athyriaceae	*Athyrium iseanum* Rosenst.
	Athyrium nipponicum (Mett.) Hance-Mett
	Athyrium wardii (Hook.) Makino
	Athyriopsis japonica (Thunb.) Ching
	Diplazium subsinuatum (Wall. ex Hook. et Grev.) Tagawa
Aspleniaceae	*Asplenium incisum* Thunb.
	Asplenium trichomanes L. Sp.

(continued)

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(continued)

Family	Species
Thelypteridaceae	*Cyclosorus acuminatus* (Houtt.) Nakai
	Macrothelypteris oligophlebia (Bak.) Ching
	Phegopteriis decursive-pinnata (Van Hall) Fee
Blechnaceae	*Woodwardia japonica* (L. F.) Sm.
Dryopteridaceae	*Arachniodes exilis* (Hance) Ching
	Arachniodes rhomboidea (Wall. ex Mett.) Ching
	Arachniodes simplicior (Makino) Ohwi.
	Cyrtomidictyum lepidocaulon (Hook.) Ching
	Cyrtomium fortunei J. Sm.
	Dryopteris atrata (Kunze) Ching
	Dryopteris championii (Benth.) C. Chr.
	Dryopteris fuscipes C. Chr.
	Dryopteris varia (L.) O. Ktze.
	Polystichum makinoi (Tagawa) Tagawa
	Polystichum Tripteron (Kze.) Presl
Polyposiaceae	*Lepisorus thunbergianus* (Kaulf.) Ching
	Pyrrosia lingua (Thunb.) Farwell
	Phymatopsis hastata (Thunb.) Kitagawa
	Lepidogrammitis drymoglossoides (Baker) Ching
	Neolepisorus ovatus (Bedd.) Ching
	Pyrrosia petiolosa (Christ) Ching
	Polypodium niponicum Mett.
Cupressaceae	*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.
	Chamaecyparis pisifera (Siebold et Zuccarini) Enelicher
	Cupressus arizonica Greene
	Cupressus duclouxiana Hichel
	Cupressus funebris Endl.
	Cupressus lusitanica Mill. cv. ZhongShan
	Fokienia hodginsii (Dunn) A. Henry et Thomas
	Juniperus formosana Hayata
	Juniperus chinensis var. Sargentii Henry
	Platycladus orientalis (Linn.) Franco
	Sabina chinensis (Linn.) Ant.
	Sabina chinensis (Linn.) Ant. var. sargentii (Henry) Cheng et L.K.Fu
	Calocedrus macrolepis Kurz
	Thujopsis dolabrata (Thunberg ex Linn. f.) Sieb. et Zucc.
Cycadaceae	*Cycas revoluta* Thunb.
Ginkgoaceae	*Ginkgo biloba* Linn.

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Family	Species
Pinaceae	*Cedrus deodara* (Roxburgh) G. Don
	Pinus armandii Franch.
	Pinus bungeana Zucc. et Endi
	Pinus densiflora Sieb. et Zucc.
	Pinus elliottii Engelmann
	Pinus massoniana Lamb.
	Pinus palustris Miller
	Pinus parviflora Siebold et Zuccarini
	Pinus rigida Miller
	Pinus sylvestris Linn. var. mongolica Litv.
	Pinus taeda Linn.
	Pinus thunbergii Parlatore
	Pseudolarix amabilis (J. Nelson) Rehder
Podocarpaceae	*Podocarpus macrophyllus* (Thunb.) Sweet
	Podocarpus nagi (Thunb.) Zoll. et Mor. ex Zoll.
Taxodiaceae	*Taxus cuspidata* Sieb. et Zucc.
	Cryptomeria fortunei Hooibrenk ex Otto et Dietr.
	Cunninghamia lanceolata (Lamb.) Hook.
	Metasequoia glyptostroboides Hu et W. C. Cheng
	Taiwania flousiana Gaussen
	Taxodium distichum (Linn.) Rich.
	Taxodium mucronatum Tenore
Taxaceae	*Taxus chinensis* (Pilger) Rehd. var. mairei (Lemee et Levl.) Cheng et L.K. Fu
Magnoliaceae	*Liriodendron chinense* (Hemsl.) Sarg.
	Magnolia officinalis (Rehd. et Wils.) Cheng subsp. biloba (Rehd.et Wils.) Law
	Magnolia heptapeta (Buchoz) Dandy
	Magnolia grandiflora L.
	Magnolia liliflora Desr.
	Magnolia sieboldii K.Koch
	Magnolia amoena Cheng
	Michelia alba DC.
	Michelia figo (Lour.) Spreng.
	Michelia chapensis Dandy
	Michelia maudiae Dunn
	Michelia platypetala Hand.-Mazz.
	Michelia wilsonii Finet et Gagnep.
	Michelia macclurei Dandy
	Michelia foveolata Merr. ex Dandy

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Family	Species
Lauraceae	*Actinodaphne lancifolia* Meissn.var.sinensis
	Litsea rotundifolia Hemsl. var. oblongifolia (Nees) Allen
	Cinnamomum camphora (L.) Presl
	Cinnamomum japonicum Sieb.
	Lindera angustifolia Cheng
	Lindera erythrocarpa Makino
	Lindera glauca (Sieb. et Zucc.) Bl.
	Lindera umbellata Thunb.
	Lindera reflexa Hemsl.
	Lindera rubronerium Gamble
	Litsea auriculata Chien et Cheng
	Litsea cubeba (Lour.) Pers.
	Machilus leptophylla Hand.-Mazz.
	Machilus pauhoi kaneh
	Machilus thunbergii Sieb. et Zucc.
	Neolitsea aurata (Hay.) Koidz.
	Phoebe sheareri (Hemsl.) Gamble
	Sassafras tzumu (Hemsl.) Hemsl.
Calycanthacerae	*Chimonanthus praecox* (L.)Link
Illiciaceae	*Illicium henryi* Diels.
Schisandraceae	*Kadsura longipedunculata* Finet et Gagnep.
	Schisandra chinensis (Turcz.) Baill.
Aristolochiaceae	*Aristolochia debilis* Sieb. et Zucc.
	Asarum forbesii Maxim.
Chloranthaceae	*Chloranthus spicatus* (Thunb.) Makino
Saururaceae	*Houttuynia cordata* Thunb.
	Saururus chinensis (Lour.) Baill.
Nymphaeaceae	*Nymphaea tetragona* Georgi
	Nuphar pumilum (Hoffm.) DC.
	Euryale ferox Salisb. ex DC.
	Brasenia schreberi J. F. Gmel.
	Nelumbo nucifera Gaertn.
Ceratophyllaceae	*Ceratophyllum demersum* Linn.
Ranunculaceae	*Clematis apiifolia* DC.
	Clematis chinensis Osbeck
	Clematis finetiana Lévl. et Vant.
	Clematis argentilucida (Lévl. et Vant.) W. T. Wang
	Ranunculus japonicus Thunb.
	Semiaquilegia adoxoides (DC.) Makino
	Thalictrum fortunei S. Moore

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Family	Species
	Coptis chinensis Franch.
	Consolida ajacis (L.) Schur
	Pulsatilla chinensis (Bunge) Regel
	Leptopyrum fumarioides (Linn.) Reichb.
	Clematis hexapetala Pall.
Berberidaceae	*Berberis silva-taroucana* Schneid.
	Berberis wilsoniae Hemsl. et Wils.
	Berberis thunbergii DC.
	Mahonia bealei (Fort.) Carr.
	Mahonia fortunei (Lindl.) Fedde
	Nandina domestica Thunb.
Lardizabalaceae	*Akebia quinata* (Thunb.) Decne.
	Akebia trifoliata (Thunb.) Koidz.
	Holboellia coriacea Deils
	Sargentodoxa cuneata (Oliv.) Rehd. et Wils.
	Stauntonia chinensis DC.
Menispermaceae	*Cocculus orbiculatus* (Linn.) DC.
	Menispermum dauricum DC.
	Cocculus trilopus.(Thunb.) DC.
	Stephania cepharantha Hay.
	Stephania japonica (Thunb.) Miers
Papaveraceae	*Papaver somniferum* Linn.
	Macleaya cordata (Willd.)R.Br
	Papaver rhoeas
	Chelidonium majus Linn.
Hamamelidaceae	*Corylopsis sinensis* Hemsl.
	Fortunearia sinensis Rehd. et Wils.
	Liquidambar formosana Hance
	Parrotia subaequalis (H.T. Chang) R.M. Hao et H.T. Wei
	Loropetalum chinense (R. Br.) Oliver
	Loropetalum chinense (R. Br.) Oliver var. rubrum Yieh
Cercidiphyllaceae	*Cercidiphyllum japonicum* Sieb. et Zucc.
Platanaceae	*Platanus ×acerifolia* (Ait.) Willd.
Eucommiaceae	*Eucommia ulmoides* Oliver
Ulmaceae	*Celtis sinensis* Pers.
	Zelkova serrata (Thunb.) Makino
	Ulmus parvifolia Jacq.
	Ulmus pumila L.
	Ulmus pumila Linn. cv. Tenue S.Y.Wang

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Family	Species
Moraceae	*Broussonetia papyifera* (Linn.) L'Hert. ex Vent.
	Broussonetia kazinoki Sieb. et Zucc.
	Cudrania tricuspidata (Carr.) Bur.
	Ficus elastica Roxb.
	Ficus pumila L.
	Ficus pumila L. cv. Minima
	Ficus carica Linn.
	Ficus sarmentosa Buch.-Ham. ex J. E. Sm. var. henryi (King et Oliv.) Corner
	Ficus sarmentosa Buch.-Ham. ex J. E. Sm. var. impressa (Champ.) Corner
	Morus alba Linn.
	Humulus scandens (Lour.) Merr.
	Cannabis sativa Linn.
Urticaceae	*Urtica fissa* E. Pritz.
	Laportea bulbifera (Sieb. et Zucc.) Wedd.
	Laportea buibifera (Sieb. et Zucc.)Wedd. Var. sinensis Chien
	Gonostegia hirta (Bl.) Miq.
	Pilea notata C. H. Wright
	Debregeasia longifolia (Burm. F.) Wedd.
	Pouzolzia zeylanica (L.) Benn.
Juglandaceae	*Carya cathayensis* Sarg.
	Carya illinoensis (Wangenheim) K. Koch
	Juglans regia Linn.
	Platycarya strobilacea Sieb. et Zucc.
	Pterocarya stenoptera C. DC.
Fagaceae	*Castanea mollissima* Bl.
	Castanea seguinii Dode
	Castanea henryi (Skan) Rehd. et Wils.
	Quercus acutissima Carr.
	Quercus variabilis Blume
	Quercus denlata Thunb.
	Lithocarpus glaber (Thunb.) Nakai
	Quercus fabri Hance
	Quercus aliena Blume
	Castanopsis fargesii Franch.
	Fagus longipetiolata Seem.
	Quercus liouana
	Castanopsis carlesii (Hemsl.) Hayata.
	Castanopsis sclerophylla (Lindl. et Paxton) Schottky
	Quercus glandulifera var.brevipetiolata Nakai

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Family	Species
Betulaceae	*Alnus japonica* (Thunb.) Steud.
	Alnus trabeculosa Hand.-Mazz.
Caryophyllaceae	*Dianthus chinensis* Linn.
	Dianthus caryophyllus Linn[a].
	Dianthus plumarius L.
	Lychnis fulgens Fischer ex Sprengel
	Melandrium apricum (Turcz.) Rohrb.
	Stellaria media (Linn.) Cyr.
	Myosoton aquaticum (Linn.) Fries
	Vaccaria segetalis (Neck.) Garcke
	Agrostemma githago Linn .
Phytolaccaceae	*Phytolacca acinosa* Roxb.
Nyctaginaceae	*Bougainvillea spectabilis* Willd[a].
	Mirabilis jalapa Linn.
Aizoaceae	*Mollugo stricta* Linn.
	Lithops pseudotruncatella (Bgr.) N.E.Br[a]
Portulacaceae	*Portulaca grandiflora* Hook.
	Portulaca oleracea
Chenopodiaceae	*Chenopodium ambrosioides* Linn.
	Spinacia oleracea Linn.
	Chenopodium album Linn.
	Kochia scoparia (Linn.) Schrad.
	Axyris amaranthoides Linn.
	Chenopodium acuminatum Willd.
	Chenopodium hybridum Linn.
	Chenopodium glaucum Linn.
	Chenopodium stenophyllum Koidz.
	Corispermum maorocarpum Bunge
	Salsola collina Pall.
	Chenopodium aristatum Linn.
Amaranthaceae	*Achyranthes aspera* Linn.
	Achyranthes bidentata Blume
	Alternanthera sessilis (Linn.) DC.
	Amaranthus ascendens Loisel.
	Celosia argentea Linn.
	Celosia cristata Linn.
	Celosia argentea Linn.

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Family	Species
Cactaceae	*Opuntia stricta* (Haw.) Haw. var. dillenii (Ker-Gawl.) Benson
	Echinopsis multiplex Zucc.
	Cereus pernambucensis Lem[a].
	Hylocereus undatus (Haw.) Britt. et Rose[a]
	Zygocactus truncatns (Haw). Schum[a]
	Epiphyllum oxypetalum (DC.) Haw[a].
	Nopalxochia ackermannii Knuth[a]
	Echinocactus grusonii Hildm[a].
Polygonaceae	*Antenoron filiforme* (Thunb.) Rob. et Vaut.
	Fagopyrum dibotrys (D.Don) Hara
	Fagopyrum esculentum Moench
	Polygonum aviculare Linn.
	Polygonum viscosum Buch.-Ham. ex D. Don
	Polygonum bungeanum Turcz.
	Polygonim bistorta Linn.
	Polygonum thunbergii Sieb. et Zucc.
	Polygonum longisetum De Bruyn
	Polygonum posumbu Buch.-Ham. ex D. Don
	Reynoutria japonica Houtt.
	Polygonum dissitiflorum Hemsl.
	Polygonim praetermissum Hk. f.
	Fallopia multiflora (Thunb.) Harald.
	Polygonum hydropiper Linn.
	Polygonum orientale Linn.
	Polygonum perfoliatum Linn.
	Rumex crispus Linn.
	Polygonum lapathifolium Linn.
	Fallopia convolvula (L.) A. Love
Paeoniaceae	*Paeonia suffruticosa* Andr.
	Paeonia lactiflora Pall.
Theaceae	*Camellia japonica* Linn.
	Camellia chekiangoleosa Hu
	Camellia oleifera Abel.
	Camellia sinensis (L.) O. Ktze.
	Cleyera japonica Thunb.
	Eurya japonica Thunb.
	Eurya muricata Dunn
	Eurya hebeclados Ling
	Schima superba Gardn. et Champ.
	Ternstroemia gymnanthera (Wight et Arn.) Beddome

(continued)

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Family	Species
Hypericaceae	*Hypericum ascyron* Linn.
	Hypericum attenuatum Choisy.
	Hypericum monogynum Linn.
	Hypericum japonicum Thunb. ex Murray
Actinidiaceae	*Actinidia chinensis* Planch.
Tiliaceae	*Tilia miqueliana* Maxim.
	Corchoropsis psilocarpa Harms et Loes. ex Loes.
	Corchoropsis tomentosa (Thunb.) Makino
	Grewia biloba G.Don
Malvaceae	*Abutilon theophrasti* Medicus
	Hibiscus syriacus Linn.
	Hibiscus trionum Linn.
	Hibiscus mutabilis Linn.
	Hibiscus rosa-sinensis L.
	Hibiscus cannabinus L.
	Abelmoschus esculentus (L.) Moench
	Gossypium herbaceum L.
	Althaea rosea (Linn.) Cavan.
	Malva sinensis Cav.
	Malva crispa Linn.
Elaeocarpaceae	*Elaeocarpus decipiens* Hemsl.
Sterculiaceae	*Firmiana platanifolia* (Linn. f.) Marsili
	Melochia corchorifolia Linn.
	Helicteres angustifolia Linn.
Violaceae	*Viola pilosa* Blume
	Viola grypoceras A. Gray
	Viola inconspicua Blume
	Viola inconspicua Bl.
	Viola philippica Cav.
	Viola yedoensis Makino
	Viola tricolor Linn.
Cucurbitaceae	*Cucurbita moschata* (Duch. ex Lam.) Duch. ex Poiret
	Momordica charantia Linn.
	Luffa cylindrica (Linn.) Roem.
	Trichosanthes anguina Linn.
	Benincasa hispida (Thunb.) Cogn.
	Luffa aegyptica
	Cucumis melo Linn. var. conomon (Thunb.) Makino
	Citrullus lanatus (Thunb.) Matsum. et Nakai
	Cucumis sativus Linn.

(continued)

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Family	Species
	Cucumis melo Linn.
	Lagenaria siceraria (Molina) Standl. var. depressa (Ser.) Hara
	Trichosanthes kirilowii Maxim.
	Gomphogyne cissiformis Griff.
	Melothria indica Lour.
	Trichosanthes cucumeroides (Ser.) Maxim.
	Lagenaria siceraria (Molina) Standl.
Tamaricaceae	*Tamarix chinensis* Lour.
Begoniaceae	*Begonia semperflorens* Link et Otto[a]
	Begonia grandis Dry.
	Begonia coccinea Hk.
	Begonia hiemalis Fotsch[a]
Salicaceae	*Populus adenopoda* Maxim.
	Salix babylonica Linn.
	Salix matsudana Koidz.
	Salix argyracea E. L. Wolf
	*Salix integr*a Thunb.
	Salix matsudana var. umbraculifera x Salix babylonica
Brassicaceae	*Brassica campestris* L.
	Brassica chinensis Linn.
	Brassica oleracea Linnaeus var. acephala Linn.f. tricolor Hort.
	Brassica oleracea Linnaeus var. capitata Linnaeus
	Brassica caulorapa Pasq.
	Brassica oleracea Linnaeus var. gemmifera Zenker
	Capsella bursa-pastoris (L.) Medic.
	Raphanus sativus L.
	Raphanus sativus L. var. radcula pers
	Raphanus acanthiformis J.M. Morel ex Sasaki
	Raphanus sativus L. (Chinensis Group) 'Red Meat'
	Brassica juncea (Linnaeus) Czernajew var. megarrhiza Tsen et Lee
	Brassica rapa L.
	Brassica alboglabra L. H. Bailey
	Brassica oleracea var.italica
	Brassica juncea (Linnaeus) Czernajew var. multiceps Tsen et Lee
	Brassica juncea (Linnaeus) Czernajew
	Brassica juncea (Linnaeus)Czernajew var.foliosa L.H.Bailey
	Brassica oleracera L. Var. Acpitata L.
	Brassica chinensis Linn.
	Beassica pekinensis (Lour.) Rupr.
	Orychophragmus violaceus (Linnaeus) O. E. Schulz

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Family	Species
	Brassica oleracea Linnaeus var. botrytis Linnaeus
	Cardamine impartiens Linn.
	Cardamine lyrata Bunge
	Erysimum cheiranthoides Linn.
	Malcolmia africana (L.) R. Br.
	Rorippa indica (Linn.) Hiern
	Descurainia sophia (Linn.) Webb ex Prantl
	Matthiola incana (Linn.) R. Br.
	Arabis pendula Linn.
	Draba nemorosa Linn.
	Lepidium apetalum Willdenow
	Rorippa globosa (Turcz.) Hayek
	Thlaspi arvense Linn.
Pittosporaceae	*Pittosporum illicioides* Makino
	Pittosporum tobira (Thunb.) Ait.
Saxifragaceae	*Saxifraga stolonifera* Curt.
	Philadelphus incanus Koehne
	Hydrangea macrophylla (Thunb.) Ser.
Crassulaceae	*Orostachys fimbriatus* (Turcz.) Berger
	Penthorum chinense Pursh
	Sedum emarginatum Migo
	Sedum aizoon L.
	Sedum erythrostictum Miq.
	Sedum sarmentosum Bunge
	Sedum aizoon Linn.[a]
	Crassula argentea[a]
	Echeveria elegans Rose[a]
	Sinocrassula indica (Decne.) Berger[a]
	Bryophyllum pinnatum (Linn. f.) Oken[a]
	Kalanchoe blossfeldiana[a]
	Crassula ovata[a]
Rosaceae	*Agrimonia pilosa* Ledeb.
	Crataegus pinnatifida Bge.
	Crataegus cuneata Sieb. et Zucc.
	Chaenomeles speciosa (Sweet) Nakai
	Chaenomeles sinensis (Thouin) Koehne
	Exochorda giraldii Hesse
	Exochorda racemosa (Lindl.) Rehd.
	Eriobotrya japonica (Thunb.) Lindl.
	Kerria japonica (Linn.) DC.

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Family	Species
	Malus asiatica Nakai
	Malus baccata (Linn.) Borkh.
	Malus halliana Koehne
	Malus hupehensis (Pamp.) Rehd.
	Malus pumila Mill.
	Photinia serrulata Lindl.
	Photinia parvifolia (Pritz.) Schneid.
	Photinia villosa (Thunb.) DC.
	Photinia serrulata
	Armeniaca vulgaris Lam.
	Prunus buergeriana Miq.
	Prunus buergeriana Miq.
	Prunus cerasifera Ehrh. cv. Atropurpurea
	Amygdalus persica Linn. var. compressa (Loud.) Yü et Lu
	Padus racemosa (Linn.) Gilib.
	Amygdalus persica Linn. var. aganonucipersica (Schübler & Martens) Yü et Lu
	Amygdalus persica Linn. var. persica f. atropurpurea Schneid.
	Amygdalus persica Linn. var. scleropersica (Reich.) Yü et Lu
	Amygdalus persica Linn. var. persica f. duplex Rehd.
	Prunus persica var. nectarina (Ait.) Maxim.
	Amygdalus persica Linn. var. densa Makino
	Amygdalus persica Linn. var. persica f. camelliaeflora (Van Houtte) Dipp.
	Cerasus japonica (Thunb.) Lois.
	Armeniaca mume Sieb.
	Prunus salicina Linn.
	Cerasus serrulata (Lindl.) G. Don ex London
	Cerasus serrulata (Lindl.) London var. pubescens (Makino) Yü et Li
	Amygdalus triloba (Lindl.) Ricker cv. Multiplex
	Potentilla discolor Bge.
	Potentilla freyniana Bornm.
	Potentilla kleiniana Wight et Arn.
	Potentilla supina Linn.
	Pyracantha fortuneana (Maxim.) Li
	Pyrus betulaefolia Bge
	Pyrus calleryana Dcne.
	Pyrus bretschneideri Rehd.
	Rosa laevigata Michx.
	Rosa chinensis jacq.
	Rosa cymosa Tratt.

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Family	Species
	Rosa henryi Boulenger.
	Rosa multiflora Thunb.
	Rosa multiflora Thunb. var. carnea Thory
	Rosa rugosa Thunb.
	Rubus corchorifolius Linn. f.
	Rubus chingii Hu
	Rubus hirsutus Thunb.
	Rubus parvifolius Linn.
	Rubus parvifolius Linn. var. adenochlamys (Focke) Migo
	Rubus swinhoei Hance
	Rubus corchorifolius L.f.
	Spiraea japonica L. F. Var. Fortunei (Pl.) Rehd.
	Spiraea prunifolia Sieb. et Zucc.
	Spiraea chinensis Maxim.
	Spiraea cantoniensis Lour.
	Sanguisorba officinalis Linn.
	Duchesnea indica (Andr.) Focke
	Fragaria ×ananassa Duch.
	Rubus idaeus Linn.
Haloragaceae	*Myriophyllum verticillatum* Linn.
Melastomataceae	*Osbeckia chinensis* Linn. ex Walp.
Polygalaceae	*Polygala arillata* Buch.-Ham.
	Polygala tenuifolia Willd.
Punicaceae	*Punica granatum* Linn.
Leguminosae	*Aeschynomene indica* L.
	Albizia julibrissin Durazz.
	Acacia farnesiana (Linn.) Willd.
	Albizia kalkora (Roxb.) Prain
	Amorpha fruticosa Linn.
	Caesalpinia decapetala (Roth) Alston
	Caragana sinica (Buc'hoz) Rehd.
	Cassia mimosoides L.
	Cassia occidentalis Linn.
	Cassia tora Linn.
	Dalbergia hupeana Hance
	Desmodium podocarpum DC.
	Desmodium caudatum (Thunb.) DC.
	Desmodium microphyllum (Thunb.) DC.
	Desmodium oldhami Oliv.
	Desmodium racemosum (Thunb.) DC.

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Family	Species
	Dunbaria villos (Thunb.) Makino
	Glycine max (Linn.) Merr.
	Glycine soja Sieb. Et Zucc.
	Indigofera pseudotinctoria Matsum
	Kummerowia stipulacea (Maxim.) Makino
	Kummerowia striata (Thunb.) Schindl.
	Lespedeza buergeri Miq.
	Lespedeza chinensis G. Don
	Lespedeza cuneata (Dum.-Cours.) G. Don
	Lespedeza formosa (Vog.) Koehne
	Lespedeza pilosa (Thunb.) Sieb. et Zucc.
	Lespedeza bicolor Turcz.
	Lespedeza tomentosa (Thunb.) Sieb.
	Melilotus indicus (L.) All.
	Millettia reticulata Benth.
	Mucuna pdrohwashanica Tang et Wang
	Ormosia hosiei Hemsl. et Wils.
	Phaseolus minimus Roxb.
	Pueraria pseudohirsuta Tang et wang
	Pueraria lobata (Willd.) Ohwi
	Lathyrus quinquenervius (Miq.) Litv.
	Robinia pseudoacacia Linn.
	Sophora japonica Linn.
	*Sophora flavescen*s Alt.
	Vicia unijuga A. Br.
	Vigna vexillata (Linn.) Rich.
	Wisteria sinensis (Sims) Sweet
	Cercis chinensis Bunge
	Cercis chinensis Bunge f. alba Hsu
	Gleditsia sinensis Lam.
	Gymnocladus chinensis Baill.
	Cladrastis platycarpa (Maxim.) Makino
	Cladrastis wilsonii Takeda
	Vicia faba Linn.
	Pisum sativum Linn.
	Vigna radiata (Linn.) Wilczek
	Vigna angularis (Willd.) Ohwi et Ohashi
	Vigna unguiculata (Linn.) Walp.
	Phaseolus vulgaris Linn.
	Lablab purpureus (Linn.) Sweet

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Family	Species
	Dumasia truncata Sieb. et Zucc.
	Cajanus cajan (Linn.) Millsp.
	Arachis hypogaea Linn.
	Astragalus sinicus Linn.
	Medicago sativa Linn.
	Medicago falcata Linn.
	Astragalus sinicus L.
	Mimosa pudica Linn.
	Canavalia gladiata (Jacq.) DC.
	Sesbania cannabina (Retz.) Poir
	Trifolium repens L.
	Trifolium pratense L.
Lythraceae	*Lagerstroemia indica* Linn.
	Lagerstroemia subcostata Koehne
	Lythrum salicaria Linn.
Onagraceae	*Circaea cordata* Royle
	Epilobium hirsutum Linn.
	Ludwigia ovalis Miq.
	Ludwigia prostrata Roxb.
	Fuchsia hybrida Hort. ex Sieb. et Voss.[a]
Thymelaeaceae	*Daphne genkwa* Sieb. et Zucc.
	Daphne odora Thunb.
	Edgeworthia chrysantha Lindl.
Elaeagnaceae	*Elaeagnus argyi* Lévl.
	Elaeagnus multiflora Thunb.
	Elaeagnus umbellata Thunb.
Trapaceae	*Trapa spinosa* Roxb.
	Trapa incisa Sieb. et Zucc. var. quadricaudata Glück.
	Trapa quadrispinosa Roxb.
Aquifoliaceae	*Ilex chinensis* Sims
	Ilex cornuta Lindl. et Paxt.
	Ilex macrocarpa Oliv.
	Ilex latifolia Thunb.
	Ilex rotunda Thunb.
Celastraceae	*Celastrus angulatus* Maxim.
	Celastrus orbiculatus Thunb.
	Euonymus alatus (Thunb.) Sieb.
	Euonymus maackii Rupr.
	Euonymus fortunei (Turcz.) Hand.-Mazz.
	Euonymus grandiflorus Wall.

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Family	Species
	Euonymus japonicus Thunb.
	Euonymus japonicus Thunb. cv. Aureus
Euphorbiaceae	*Acalypha australis* Linn.
	Alchornea davidii Franch.
	Vernicia fordii (Hemsl.) Airy Shaw
	Bischofia polycarpa (Levl.) Airy Shaw
	Euphorbia pekinensis Rupr.
	Euphorbia humifusa Willd.
	Euphorbia pekinensis Rupr.
	Euphorbia pulcherrima Willd. ex Klotzsch[a]
	Excoecaria cochinchinensis Lour
	Cleistanthus tonkinensis Jabl.
	Mallotus japonicus (Thunb.) Muell. Arg. var. floccosus (Muell.Arg.)S. M.Hwang
	Mallotus apelta (Lour.)Muell.Arg.
	Mallotus repandus (Willd.) Muell. Arg. var. chrysocarpus (Pamp.)S. M. Hwang
	Phyllanthus glaucus Wall. ex Muell. Arg
	Phyllanthus matsumurae Hayata
	Phyllanthus urinaria Linn.
	Ricinus communis Linn.
	Sapium sebiferum (Linn.) Roxb.
	Flueggea suffruticosa (Pall.) Baill.
	Euphorbia helioscopia Linn.
Buxaceae	*Buxus harlandii* Hance
	Buxus bodinieri Levl.
Rhamnaceae	*Berchemia floribunda* (Wall.) Brongn.
	Paliurus hemsleyanus Rehd.
	Paliurus ramosissimus (Lour.) Poir.
	Hovenia acerba Lindl.
	Rhamnus crenata Sieb. et Zucc.
	Rhamnus cathartica Linn.
	Rhamnus globosa Bunge
	Rhamnus utilis Decne.
	Sageretia thea (Osbeck) Johnst.
	Ziziphus jujuba Mill.
Vitaceae	*Ampelopsis brevipedunculata* (Maxim.) Trautv.
	Ampelopsis japonica (Thunb.) Makino
	Parthenocissus thomsonii (Laws.) Planch.
	Parthenocissus tricuspidata (S. Et Z.) Planch.

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Family	Species
	Vitis amurensis Rupr.
	Vitis davidii (Roman. Du Caill.) Foex.
	Vitis flexuosa Thunb.
	Vitis heyneana Roem. et Schult
	Vitis vinifera Linn.
Sapindaceae	*Koelreuteria paniculata* Laxm.
	Sapindus mukorossi Gaertn.
Hippocastanaceae	*Aesculus chinensis* Bunge
Aceraceae	*Acer davidii* Franch.
	Acer ginnala Maxim.
	Acer cinnamomifolium Hayata
	Acer buergerianum Miq.
	Acer negundo
	Acer palmatum Thunb.
	Acer truncatum Bunge
	Acer mono Maxim.
	Acer japonicum Thunb.
	Acer palmatum
	Acer rubrum L.
Staphyleaceae	*Euscaphis japonica* (Thunb.) Dippel
	Tapiscia sinensis Oliv.
Meliaceae	*Aglaia odorata* Lour.
	Melia azedarach Linn.
	Melia toosendan Sieb. et Zucc.
	Toona sinensis (A. Juss.) Roem.
Anacardiaceae	*Pistacia chinensis* Bunge
	Choerospondias axillaria (Roxb.) Burtt et Hill
	Rhus chinensis Mill.
	Toxicodendron vernicifluum (Stokes) F.A.Barkl.
	Toxicodendron sylvestre (Sieb. et Zucc.) O.Ktze.
	Toxicodendron succedaneum (L.) O. Ktze.
	Cotinus coggygria Scop.
	Cotinus coggygria Royal purple
	Rhus typhina L.
Zygophyllaceae	*Tribulus terrester* Linn.

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Family	Species
Rutaceae	*Citrus aurantium* Linn. cv. Daidai
	Citrus medica Linn.
	Fortunella margarita (Lour.) Swingle[a]
	Citrus medica Linn. var. sarcodactylis (Noot.) Swingle[a]
	Citrus microcarpa Bge.
	Fortunella margarita (Lour.) Swingle
	Dictamnus dasycarpus Turcz.
	Enodia fargesii Dode
	Evodia rutaecarpa (Juss.) Benth.
	Murraya exotica L. Mant.
	Poncirus trifoliata Raf.
	Zanthoxylum ailanthoides Sied. et. Zucc.
	Zanthoxylum simulans Hance
	Zanthoxylum schinifolium Sieb. et Zucc.
	Zanthoxylum simulans Hance
	Zanthoxylum acanthopodium DC.
Oxalidaceae	*Oxalis corniculata* Linn.
	Oxalis corymbosa DC.
	Oxalis triangularis
Geraniaceae	*Geranium krameri* Franch. et Sav.
	Geranium Wilfordii Maxim.
	Pelargonium hortorum Bailey[a]
Balsaminaceae	*Impatiens balsamina* Linn.
	Impatiens hawkeri
	Impatiens wallerana[a]
Araliaceae	*Acanthopanax graciliastylus* W.W.Smith
	Aralia chinensis Linn.
	Aralia cordata Thunb.
	Fatsia japonica (Thunb.) Decne. et Planch.
	Hedera nepalensis K. Koch var. sinensis (Tobl.) Rehd.
	Schefflera octophylla (Lour.) Harms[a]
Umbelliferae	*Ostericum grosseserratum* (Maxim.) Kitagawa
	Bupleurum chinense DC.
	Bupleurum scorzonerifolium Willd.
	Centella asiatica (Linn.) Urban
	Cnidium monnieri (Linn.) Cuss.
	Cryptotaenia japonica Hassk.
	Daucus carota Linn. var. sativa Hoffm.
	Daucus carota Linn.
	Peucedanum praeruptorum Dunn

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Family	Species
	Peucedanum pracruptorum Dunn
	Sanicula chinensis Bunge
	Coriandrum sativum Linn.
	Ostericum sieboldii (Miq.) Nakai
	Apium graveolens Linn.
	Apium graveloens L.
	Osmorhiza aristata (Thunb.) Makino et Yabe
	Foeniculum vulgare Mill.
	Changium smyrnioides Wolff
	Hudrocotyle verticillata
Ericaceae	*Rhododendron mariesii* Hemsl. et Wils.
	Rhododendron molle (Blum) G. Don
	Rhododendron ovatum (Lindl.) Planch.
	Rhododendron simsii Planch.
	Rhododendron fortunei Lindl.
	Rhododendron mucronatum (Blume) G. Don
	Lyonia ovalifolia (Wall.) Drude var. Elliptica (S. Et Z.) H. -M.
	Vaccinium mandarinorum Diels
	Vaccinium bracteatum Thunb.
Ebenaceae	*Diospyros armata* Hemsl.
	Diospyros kaki Thunb.
	Diospyros kaki Thunb. var. silvestris Makino
	Diospyros lotus Linn.
	Diospyros rhombifolia Hemsl.
Symplocaceae	*Symplocos setchuensis* Brand
	Symplocos stellaris Brand
	Symplocos paniculata (Thunb.) Miq.
Styracaceae	*Styrax confusus* Hemsl.
	Styrax japonicus Sieb. et Zucc.
	Styrax dasyanthus Perk.
	Sinojackia xylocarpa Hu
	Mirabilis jalapa Linn.
Primulaceae	*Androsace umbellata* (Lour.) Merr.
	Lysimachia capillipes Hemsl.
	Lysimachia clethroides Duby
	Lysimachia christinae Hance
	Lysimachia fortunei Maxim.
	Lysimachia klattiana Hance
	Lysimachia parvifolia Franch. ex Hemsl.
	Lysimachia grammica Hance[a]

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Family	Species
	Lysimachia pentapetala Bunge[a]
	Lysimachia stenosepala Hemsl.
	Primula malacoides Franch.
	Cyclamen persicum Mill.
Loganiaceae	*Buddleja lindleyana* Fort.
Apocynaceae	*Nerium indicum* Mill.
	Trachelospermum jasminoides (Lindl.) Lem.
Asclepiadaceae	*Cynanchum auriculatum* Royleex Wight
	Cynanchum paniculatum (Bunge) Kitagawa
	Cynanchum thesioides (Freyn) K. Schum.
	Metaplexis japonica (Thunb.) Makino
	Periploca sepium Bunge
Gentianaceae	*Gentiana scabra* Bunge
	Swertia dilute (Turcz.)Bemth. Et Hook.f.
	Nymphoides peltatum (Gmel.)O.Kuntze
Convolvulaceae	*Cuscuta chinensis* Lam.
	Cuscuta japonica Choisy
	Porana racemosa Roxb.
	Ipomoea coccinea L.
	Quamoclit pennata(Lam.)Bojer
	Pharbitis nil (L.) Ching
	Pharbitis purpurea (Linn.) Voigt
	Ipomoea aquatica Forsskal
	Calystegia sepium (L.) R.Br.
	Ipomoea batatas (L.) Lamk.
	Porana racemosa Roxb.
	Calystegia pellita (Ledeb.) G. Don
	Convolvulus arvensis Linn.
Solanaceae	*Atropa belladonna* Linn.
	Solanum melongena L
	Datura innoxia Miller
	Datura metel Linn.
	Datura stramonium Linn.
	Cestrum nocturnum Linn.
	Lycium chinense Miller
	Physalis angulata L.
	Physalis alkekengi Linn.
	Physaliastrum heterophyllum (Hemsley) Migo
	Solanum japonense Nakai
	Solanum lyratum Thunberg

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Family	Species
	Lycopersicon esculentum Miller
	Capsicum annuum Linn.
	Solanum tuberosum L.
	Solanum pseudocapsicum L.
	Capsicum frutescans
	Hyoscyamus niger Linn.
	Solanum nigrum Linn.
Boraginaceae	*Lithospermum zollingeri* A. DC.
	Lappula myosotis Moench
	Trigonotis peduncularis (Trev.) Benth. ex Baker et Moore
Verbenaceae	*Callicarpa bodinieri* Levl.
	Callicarpa cathayana H. T. Chang
	Callicarpa giraldii Hesse ex Rehd.
	Caryopteris divaricata Maxim.
	Clerodendrum cyrtophyllum Turcz.
	Clerodendrum bungei Steud.
	Clerodendrum trichotomum Thunb.
	Lantana camara Linn.
	Premna microphylla Turcz.
	Vitex negundo Linn.
	Vitex negundo Linn. var. cannabifolia (Sieb. et Zucc.) Hand.-Mazz.
	Verbena hybrida Voss
Labiatae	*Agastache rugosa* (Fisch. et Mey.) O. Ktze.
	Ajuga ciliata Bunge
	Ajuga nipponensis Makino
	Clinopodium chinense (Benth.) O. Ktze.
	Clinopodium gracile (Benth.) Matsum.
	Chelonopsis chekiangensis C. Y. Wu
	Elsholtzia saxatilis (Komarov) Nakai ex Kitagawa
	Elsholtzia ciliata (Thunb.) Hyland.
	Rabdosia amethystoides (Benth.) Hara
	Keiskea elsholtiiides Merr.
	Keiskea sinensis Diels
	Leonurus artemisia (Lour.) S. Y. Hu
	Lycopus lucidus Turcz.
	Mentha haplocalyx Briq.
	Mosla chinensis Maxim.
	Mosla scabra (Thunb.) C.Y.Wu et H.W.Li
	Mosla dianthera (Buch.-Ham. ex Roxburgh) Maxim.
	Perilla frutescens (L.) Britton

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Family	Species
	Perilla frutescens (Linn.) Britt.
	Salvia chinensis Benth.
	Salvia miltiorrhiza Bunge
	Scutellaria indica Linn.
	Teucrium pernyi Franch.
	Teucrium viscidum Bl.
	Prunella vulgaris Linn.
	Lagopsis supina (Steph. ex Willd.) Ik.-Gal. ex Knorr.
	Lamium amplexicaule Linn.
	Amethystea caerulea Linn.
	Galeopsis bifida Boenn.
	Salvia splendens Ker-Gawler
	Scutellaria baicalensis Georgi
	Stachys japonica Miq.
Scrophulariaceae	*Veronicastrum axillare* (Sieb. et Zucc.) Yamazaki
	Buchnera cruciata Buch. Mutis ex. Linn. f. Hamilt.
	Centranthera cochinchinensis (Lour.) Merr.
	Limnophila sessiliflora (Vahl) Blume
	Lindernia angustifolia (Benth.) Wettst.
	Lindernia crustacea (Linn.) F. Muell
	Lindernia procumbens (Krock.) Borbas
	Mazus japonicus (Thunb.) O. Kuntze
	Melampyrum roseum Maxim.
	Monochasma savatieri Franch. ex Maxim.
	Monochasma sheareri Maxim. ex Franch. et Savat.
	Omphalothrix longipes Maxim.
	Paulownia tomentosa (Thunb.) Steud.
	Paulownia fargesii Franch.
	Paulowinia fortunei (Seem.)Hemsl.
	Phtheirospermum japonicum (Thunb.) Kanitz
	Scrophularia ningpoensis Hemsl.
	Siphonostegia chinensis Benth.
	Veronica didyma Tenore
	Veronica linariifolia Pall. ex Link
	Antirrhinum Majus L.
Campanulaceae	*Adenophora humanensis* Nannf.
	Adenophora stenanthina (Ledeb.) Kitagawa
	Adenophora tetraphylla (Thunb.) Fisch.
	Lobelia chinensis Lour.
	Codonopsis lanceolata (Sieb. et Zucc.) Trautv.
	Platycodon grandiflorus (Jacq.) A. DC.
	Wahlenbergia marginata (Thunb.)A. DC.

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Family	Species
Oleaceae	*Chionanthus retusus* Lindl. et Paxt.
	Forsythia viridissima Lindl.
	Forsythia suspensa (Thunb.) Vahl
	Fontanesia fortunei Carr.
	Fraxinus chinensis Roxb.
	Fraxinus insularis Hemsl.
	Jasminum nudiflorum Lindl.
	Jasminum floridum Bge.
	Jasminum sambac (L.)Ait.
	Jasminum mesnyi Hance
	Ligustrum lucidum Ait.
	Ligustrum lucidum Ait. f. latifolium (Cheng)Hsu
	Ligustrum quihoui Carr.
	Ligustrum Vicaryi Rehd.
	Ligustrum sinense Lour.
	Ligustrum obtusifolium Sieb. et Zucc.
	Olea europaea Linn.
	Osmanthus fragrans (Thunb.) Lour.
	Syringa oblata Lindl.
Bignoniaceae	*Campsis grandiflora* (Thunb.) Schum.
	Campsis radicans (L.) Seem.
	Catalpa bungei C.A.Mey
	Catalpa ovata G.Don
Gesneriaceae	*Boea hygrometrica* (Bunge) R. Br.
	Hemiboea subcapitata Clarke
	Sinningia speciosa (Lodd.) Hiern[a]
Rubiaceae	*Adina rubella* Hance
	Sinoadina racemosa (Sieb. et Zucc.) Ridsd.
	Galium aparine Linn. var. tenerum Gren.et Godr.) Rebb.
	Galium verum Linn.
	Gardenia jasminoides
	Gardenia jasminoides Ellis
	Hedyotis auriclaria Linn.
	Hedyotis diffusa Willd.
	Damnacanthus indicus (Linn.) Gaertn. F.
	Hedyotis chrysotricha (Palib.) Merr.
	Ophiorrhiza japonica Bl.
	Paederia scandens (Lour.) Merr.
	Rubia cordifolia Linn.
	Serissa japonica (Thunb.) Thunb. Nov. Gen.
	Serissa serissoides (DC.) Druce
	Emmenopterys henryi Oliv.

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Family	Species
Caprifoliaceae	*Lonicera japonica* Thunb.
	Lonicera maackii Rupr.Maxim.
	Sambucus chinensis Lindl.
	Sambucus williamsii Hance
	Viburnum erosum Thunb.
	Viburnum dilatatum Thunb.
	Viburnum setigerum Hance
	Viburnum odoratissinum Ker.-Gawl.
	Viburnum melanocarpum Hsu
	Viburnum macrocephalum Fort. var. macrocephalum f. keteleeri (Carr.) Rehd.
	Weigela coraeensis Thunb.
Nyssaceae	*Camptotheca acuminata* Decne.
	Nyssa sinensis Oliv.
	Davidia involucrata Baill.
Daphniphyllaceae	*Daphniphyllum oldhami* (Hemsl.) Rosenth.
	Daphniphyllum macropodum Miq.
Betulaceae	*Corylus heterophylla* Fisch. ex Trautv. var. sutchuenensis Franch.
	Carpinus turczaninowii Hance
Sabiaceae	*Meliosma oldhamii* Maxim.
	Sabia japonica Maxim.
Santalaceae	*Thesium chinense* Turcz.
Olacaceae	*Schoepfia jasminodora* Sieb. et Zucc.
Cornaceae	*Dendrobenthamia japonica* (DC.) Fang var. chinensis (Osborn) Fang
	Cornus officinalis Sieb. et Zucc.
	Swida walteri (Wanger.) Sojak
	Swida alba Opiz
	Bothrocaryum controversum (Hemsl.) Pojark.
	Aucuba chinensis Benth.
Alangiaceae	*Alangium platanifolium* (Sieb. et Zucc.) Harms A. chinense (Lour.) Harms.
	Alangium chinense (Lour.) Harms
Phrymaceae	*Phryma leptostachya* Linn. subsp. asiatica (Hara)Kitamura
Valerianaceae	*Patrinia angustifolia* Hemsl.
	Patrinia scabiosaefolia Fisch
Compositae	*Ainsliaea glabra* Hemsl.
	Cirsium setosum (Willd.) MB.
	Atractylodes lancea (Thunb.) DC.
	Artemisia annua Linn.
	Artemisia scoparia Waldst. et Kit.

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Family	Species
	Artemisia sieversiana Ehrhart ex Willd.
	Artemisia anomala S. Moore
	Artemisia capillaris Thunb.
	Chrysanthemum coronarium Linn.
	Artemisia sacrorum Ledeb.
	Artemisia japonica Thunb.
	Artemisia lactiflora Wall. ex DC.
	Artemisia sylvatica Maxim.
	Artemisia argyi Levl. et Vant.
	Artemisia selengensis Turcz.
	Aster ageratoides Turcx.
	Aster panduratus Nees ex Walper
	Doellingeria scaber (Thunb.) Nees
	Kalimeris indica (Linn.) Sch.-Bip.
	Emilia sonchifolia (Linn.) DC.
	Erigeron annuus (Linn.) Pers.
	Bidens pilosa Linn.
	Bidens tripartita L.
	Carpesium abrotanoides Linn.
	Carpesium cernuum Linn.
	Carpesium divaricatum Sieb. et Zucc.
	Cirsium lineare (Thunb.) Sch.-Bip.
	Dendranthema indicum (Linn.) Des Moul.
	Eclipta prostrata (Linn.) Linn.
	Conyza Canadensis (L.) Cronq.
	Eupatorium chinense L.
	Eupatorium japonicum Thunb.
	Eupatorium lindleyanum DC.
	Gnaphalium affine D.Don
	Siegesbeckia pubescens Makino
	Gynura segetum (Lour.) Merr.
	Helianthus tuberosus Linn.
	Arctium lappa Linn.
	Carduus nutans Linn.
	Hemistepta lyrata (Bunge) Bunge
	Inula japonica Thunb.
	Ixeris japonica (Burm. F.) Nakai
	Ixeris polycephala Cass.
	Kalimeris indica (Linn.) Sch.-Bip.
	Kalimeris integrifolia Turcz. ex DC.

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Family	Species
	Aster lavanduliifolius Hand.-Mazz.
	Lactuca formosana Maxim.
	Lagedium sibiricum (Linn.) Sojak
	Lactuca raddeana Maxim.var.elata (Hemsl.) Kitam.
	Lactuca sativa Linn.
	Sonchus oleraceus Linn.
	Lactuca sativa Linn. var. ramosa Hort.
	Chrysanthemum nankingense (Hand.-Mazz.) X.D.Cui
	Ligularia stenocephala (Maxim.) Matsum. et Koidz.
	Gerbera anandria (Linn.) Sch.-Bip.
	Picris hieracioides Linn.
	Pyrethrum cinerariifolium Trev.
	Solidago decurrens Lour.
	Saussurea japonica (Thunb.) DC.
	Scorzonera albicaulis Bunge
	Scorzonera austriaca Willd.
	Senecio scandens Buch.-Ham. ex D. Don
	Siegesbeckia glabrescens Makino
	Syneilesis aconitifolia (Bunge) Maxim.
	Xanthium sibiricum Patrin ex Widder
	Youngia japonica (Linn.) DC.
	Helianthus annuus Linn.
	Taraxacum mongolicum Hand.-Mazz.
	Tagetes erecta Linn.
	Tagetes patula Linn.
	Centaurea cyanus Linn.
	Calendula officinalis L.
	Dendranthema morifolium (Ramat.) Tzvel.
	Zinnia elegans Jacq.
	Pericallis hybrida B. Nord.
	Cichorium intybus Linn.
	Gerbera jamesonii Bolus
	Senecio cineraria
	Callistephus chinensis (Linn.) Nees
Plantaginaceae	*Plantago asiatica* L.
Lentibulariaceae	*Utricularia vulgaris* Linn.
Acanthaceae	*Asystasiella neesiana* (Wall.) Lindau
	Hygrophila salicifolia (Vahl) Nees
	Peristrophe japonica (Thunb.) Bremek.
	Rostellularia procumbens (Linn.) Nees

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Family	Species
Orobanchaceae	*Aeginetia indica* Linn.
Plumbaginaceae	*Limonium sinuatum*
Typhaceae	*Typha orientalis* Presl
Aponogetonaceae	*Aponogeton lakhonensis* A. Camus
Alismataceae	*Alisma plantago-aquatica* Linn.
	Sagittaria trifolia Linn. var. sinensis (Sims) Makino
	Sagittaria trifolia Linn.
Commelinaceae	*Commelina communis* Linn.
	Murdannia triquetra (Wall. ex C. B. Clarke) Bruckn.
	Setcreasea pallida
Potamogetonaceae	*Potamogeton malaianus* Miq.
	Potamogeton crispus Linn.
Butomaceae	*Hydrocleis nymphoides* Buchenau
Hydrocharitaceae	*Vallisneria natans* (Lour.) Hara
	Hydrilla verticillata (Linn. f.) Royle
Gramineae	*Oryza sativa* Linn.
	Triticum aestivum Linn.
	Hordeum vulgare Linn.
	Avena fatua Linn.
	Lolium temulentum Linn.
	Zizania latifolia (Griseb.) Stapf
	Zizania caduciflora (Turcz.) Hand.-Mazz.
	Zea mays L.
	Sorghum bicolor (Linn.) Moench
	Sorghum sudanense (Piper) Stapf
	Saccharum officinarum Linn.
	Arundinella anomala Stend.
	Bambusa multiplex (Lour.) Raeuschel ex J. A. et J. H. Schult.
	Brachystachyum densiflorum (Rendle) Keng
	Cymbopogon citratus (dC.) Stapf
	Cymbopogon goeringii (Steud.) A.Camus
	Coix lacryma-jobi Linn.
	Deyeuxia arundinacea (Linn.) Beauv.
	Indocalamus latifolius (Keng) McClure
	Indocalamus migoi (Nakai) Keng f.
	Lophatherum gracile Brongn.
	Oplismenus undulatifolius (Arduino) Beauv.
	Phyllostachys bambusoides Sieb. et Zucc.
	Phyllostachys heteroclada Oliver
	Phyllostachy angusta McClure

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Family	Species
	Phyllostachys glabrata S. Y. Chen et C. Y. Yao
	Phyllostachys bambusoides var. castillonis -inversa
	Phyllostachys bambusoides var. castillonis (Marliac ex Carriere) Makino
	Sasa argenteostriatus
	Sasa fortunei (Van Houtte) Fiori
	Bambusa multiplex (Lour.) Raeuschel ex J. A. et J. H. Schult. var. multiplex cv. Fernleaf R.A.Young
	Sinocalmus affinis (Rendle) Mcclure
	Bambusa albo-lineata (McClure) Chia
	Phyllostachys nuda McClure
	Phyllostachys nigra (Lodd.) Munro
	Phyllostachys heterocycla (Carr.) Mitford cv. Pubescens Mazel ex H.de leh.
	Phyllostachys heterocycla (Carr.) Mitford cv. Gracilis W. Y. Hsiung
	Dendrocalamus membramaceus Munro
	Phyllostachys sulphurea (Carr.) A. et C. Riv cv. Viridis R. A. Young
	Pleioblastus amarus (Keng) Keng f.
	Pseudosasa amabilis (McClure) Keng f.
	Phyllostachys propinqua McClure
	Bambusa ventricosa McClure
	Ischaemum aristatum Linn. var. glaucum (Honda) T. Koyama
	Phaenosperma globosa Munro ex Benth.
	Sorghum nitidum (Vahl) Pers.
	Setaria viridis (Linn.) Beauv.
	Themeda japonica (Willd.) Tanaka
	Phragmites australis (Cav.) Trin. ex Steud.
	Arundo donax Linn.
	Digitaria sanguinalis (Linn.) Scop.
	Digitaria ischaemum (Schreb.) Schreb.
	Eleusine indica (Linn.) Gaertn.
	Imperata cylindrica (Linn.) Beauv.
	Festuca elata Keng ex E. Alexeev
	Poa annua Linn.
	Echinochloa crusgali (Linn.) Beauv.
	Leptochloa chinensis (Linn.) Nees
	Alopecurus aequalis Sobol.
	Alopecurus japonicus Steud.
	Beckmannia syzigachne (Steud.) Fern.
	Lolium perenne Linn.
	Zoysia matrella (Linn.) Merr.

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Family	Species
	Cynodon dactylon (Linn.) Pers.
	Agrostis matsumurae Hack. ex Honda
	Eleusine indica (Linn.) Gaertn.
	Eragrostis pilosa (Linn.) Beauv.
	Eragrostis minor Host
	Eriochloa villosa (Thunb.) Kunth
	Arthraxon hispidus (Trin.) Makino
Cyperaceae	*Carex sendaica* Fanch.
	Carex leucochlora Bunge
	Carex lanceolata Boott
	Cyperus rotundus Linn.
	Fimbristylis miliacea (L.) Vahl
	Kyllinga brevifolia Rottb. Var. Leiolepis (Franch. Et Sav.)Hara
	Scirpus yagara Ohwi
	Heleocharis yokoscensis (Franch. et Savat.) Tang et Wang
	Lepiironia articulata (Retz) Domin
	Cyperus rotundus L.
	Cyperus difformis Linn.
	Heleocharis dulcis (Burm. F.) Trin. ex Henschel
	Scirpus validus Vahl
	Cyperus alternifolius Linn. subsp. flabelliformis (Rottb.) Kukenth.
Palmae	*Rhapis excelsa* (Thunb.) Henry ex Rehd.
	Trachycarpus fortunei (Hook.) H. Wendl.
Araceae	*Acorus tatarinowii* Schott
	Arisaema japonicum Blume
	Arisaema amuremse Maxim. var. serratum Nakai
	Pinellia pedatisecta Schott
	Pinellia ternata (Thunb.) Breit.
	Anthurium andraeanum[a]
	Colocasia esculenta (L.) Schott.
	Pistia stratiotes Linn.
	Zantedeschia aethiopica (Linn.) Spreng.[a]
Lemnaceae	*Lemna paucicostata* Hegelm.—Lemna perpusilla Torr.
	Spirodela polyrrhiza (Linn.) Schleid.
	Wolffia arrhiza (L.)Wimm.—Lemna arrhiza L.
Eriocaulaceae	*Eriocaulon buergerianum* Koern.
Pontederiaceae	*Monochoria korsakowii* Regel et Maack
	Monochoria vaginalis (Burm. F.) Presl ex Kunth
	Eichhornia crassipes (Mart.) solms

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Family	Species
Juncaceae	*Juncus effusus* Linn.
Stemonaceae	*Stemona japonica* (Bl.) Miq
	Stemona sessilifolia (Miq.) Miq
Liliaceae	*Allium macrostemon* Bunge
	Asparagus cochinchinensis (Lour.) Merr.
	Hemerocallis minor Mill
	Asparagus officinalis Linn.
	Allium tuberosum Rottler ex Spreng.
	Allium fistulosum Linn.
	Allium cepa Linn.
	Allium sativum Linn.
	Cardiocrinum giganteum (Wall.) Makino
	Haworthia cymbiformis Haw.
	Hemerocallis fulva (Linn.) Linn.
	Hosta plantaginea (Lam.) Aschers.
	Hosta ventricosa (Salisb.) Stearn
	Lilium pumilum DC.
	Lilium brownii F. E. Brown ex Miellez var. viridulum Baker
	Ophiopogon bodinieri Levl.
	Paris polyphylla Smith
	Polygonatum cyrtonema Hna
	Polygonatum odoratum (Mill.) Druce
	Polygonatum zanlanscianense Pamp.
	Reineckia carnea (Andr.) Kunth
	Rohdea japonica (Thunb.) Roth
	Scilla scilloides (Lindl.) Druce
	Smilacina japonica A. Gray
	Smilax china Linn.
	Smilax glabra Roxb.
	Smilax riparia A. DC.
	Smilax sieboldii Miq.
	Tricyrtis macropoda Miq.
	Ophiopogon japonicus (Linn. f.) Ker-Gawl.
	Aloe vera (Linn.) N. L. Burman var. chinensis (Haw.) Berg. [a]
	Tulipa gesneriana Linn.[a]
	Hyacinthus orientalis L.[a]
	Asparagus setaceus (Kunth) Jessop[a]
	Chlorophytum comosum (Thunb.) Baker[a]
	Aloe arborescens Mill.[a]
	Aloe variegata[a]

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Family	Species
Agavaceae	*Agave americana* Linn.[a]
	Yucca gloriosa Linn.
	Sansevieria trifasciata Prain[a]
	Nolina recurvata[a]
Amaryllidaceae	*Curculigo orchioides* Gaertn.
	Lycoris aurea (L'Her.) Herb.
	Lycoris radiata (L'Her.) Herb.
	Narcissus tazetta Linn. var. chinensis M.Roener
	Polianthes tuberosa Linn.
	Hippeastrum rutilum (Ker-Gawl.) Herb.[a]
	Clivia miniata Regel Gartenfl.[a]
	Zephyranthes candida (Lindl.)Herb.
	Haemanthus albiflos Jacq.
Iridaceae	*Belamcanda chinensis* (Linn.) Redouté
	Iris tectorum Maxim.
	Gladiolus gandavensis Van Houtte[a]
	Iris lactea Pall. var. chinensis (Fisch.) Koidz.
	Iris japonica Thunb.
	Tigridia pavonia (L. F.) Ker-Gawl.[a]
Musaceae	*Musa basjoo* Sieb. et Zucc.
Cannaceae	*Canna indica* Linn.
Bromeliaceae	*Ananas comosus* (Linn.) Merr.[a]
	Cryptanthus acaulis Beer.[a]
Marantaceae	*Maranta arundinacea* Linn.[a]
Dioscoreaceae	*Dioscorea opposita* Thunb.
Zingiberaceae	*Zingiber mioga* (Thunb.) Rosc.
	Zingiber officinale Roscoe
	Curcuma longa Linn.
Orchidaceae	*Cymbidium goeringii* (Rchb. f.) Rchb. F.
	Cymbidium sinense (Jackson ex Andr.) Willd.[a]
	Cymbidium ensifolium (Linn.) Sw.[a]
	Cymbidium faberi Rolfe
	Goodyera repens (L.) R. Br.
	Habenaria dentata (Sw.) Schltr.
	Peristylus flagellifer (Makino) Ohwi
	Cleisostoma sagittiforme Garay
	Goodyera schlechtendaliana Rchb. F.
	Phalaenopsis aphrodita Rchb. F.[a]
	Cymbidium hookerianum Rchb. F.[a]
	Demdrobium nobile[a]
	Bletilla striata (Thunb.) Reichb.f. [a]

[a]Introduced plants and cultivated by indoor pots

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