I. POLICY AND LEGAL FRAMEWORK

In October 2015, the proposed 13th “Five-Year plan” for economic and social development in China included various new policies aimed for natural forest protection mainly focused on banning commercial harvest of natural forest and increasing forest area and stock. The State Forestry Administration adopted this proposal and started a pilot project in Heilongjiang province. By the end of 2015, commercial timber harvests of state-owned natural forest areas in north-eastern Inner Mongolia has been banned. Furthermore, we are glad to witness the nation-wide implementation of this policy by the end of 2017. The new policies call for higher standards in plantation development and management in order to meet the increased domestic consumptions on forestry products.

In December 2014, the State Council passed the ‘State Owned Forestry Farm Reform Plan’ and the ‘Guide on State Owned Forestry Farm Reform’. According to the documents, state-owned forestry farms will focus on ecological protection and guarantee staff’s livelihood through innovations in management and monitoring system in future. According to the guideline, state-owned forestry farms should undergo a role-switch from timber production machinery to the role of ecological reparation units. There is also the need to setup new mechanisms to foster forest resources and support ecological system conservation.

In 2013, the State Council released documents on speeding up modern agriculture development and supporting rural area development, in which the concept of strengthening national timber strategic reserve base was mentioned. According to the State Council’s requirements on developing the timber security system, the State Forestry Administration developed the ‘Outline of national timber strategic reserve base (2013-2020)’, which planned to develop 18 bases in 6 regions involving 25 provinces, with a total base area reaching 14 million ha in year 2020. Among the 95 tree species selected for national timber strategic reserve base construction, poplar was included. ‘The national forest nursery and seeding plan (2011-2015)’ required adoption of research results based on forest nursery and seeding and set up of bases with quality-improved seedlings. The plan was aimed on improvements in variety selection methods of over 70 main afforestation species, using genetical technologies to improve breeding techniques, which also included researches on transgenic poplars.

II. TECHNICAL INFORMATION

1. Identification, registration and varietal control

1.1 Test and examination of new varieties
In 2000, the Protection Office of New Plant Variety in the State Forestry Administration (SFA) listed poplar and willow in the second directory of tree species, which was for protection of new varieties. According to the announcements of SFA during the last four years, 38 poplar clones and 9 willow clones were registered and defined as new varieties according to national *Guidelines for the conduct of tests for DUS* – willow (GB/T 26910-2011) and -poplar (GB/T 32344-2015).

**1.2 Authorization of improved varieties**

Poplar and willow clones must be tested and authorized on the provincial and national level before their cultivation and plantation in China. According to the announcements of SFA during the last four years, 14 poplar varieties were approved and added to the national list of genetically improved tree varieties issued by the National Review Committee on Improved Tree Species/Varieties, SFA. In addition, some poplar varieties and willow varieties were approved as improved varieties by the seedling stations in each province.
Table 1 – Clones under examination by the Bureau of National Forestry for registration as commercial cultivars in 2012-2015

<table>
<thead>
<tr>
<th>Latin Name</th>
<th>Source</th>
<th>Gende r</th>
<th>Breeder</th>
<th>Characteristics</th>
<th>Usage</th>
<th>Suitable Areas for Planting</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. deltoides</em> ‘Nanyang’</td>
<td><em>P. deltoides</em> ‘Bartr’ × <em>P. deltoides</em> ‘2KEN8’</td>
<td>Male</td>
<td>Research Institute of Forestry(RIF) of the Chinese Academy of Forestry</td>
<td>Fast growing, high survival rate, straight trunk, narrow crown, excellent wood property, suitable for industrial timber.</td>
<td>timber forest</td>
<td>Shandong, Henan, Hunan and Hubei Province, etc.</td>
</tr>
<tr>
<td><em>P. deltoides</em> ‘Danhongyang’</td>
<td><em>P. deltoides</em> ‘Bartr’ × <em>P. deltoides</em> cl. ‘10/17’</td>
<td>Female</td>
<td>Research Institute of Forestry(RIF) of the Chinese Academy of Forestry</td>
<td>Fast growing, high survival rate, straight trunk, narrow crown, excellent wood property, suitable for industrial timber.</td>
<td>timber forest</td>
<td>Beijing, Hebei, Shandong and Henan Province, etc.</td>
</tr>
<tr>
<td><em>P. euramericana</em> ‘2012’</td>
<td>Introduced from Italy</td>
<td>Female</td>
<td>Research Institute of Forestry(RIF) of the Chinese Academy of Forestry</td>
<td>Fast growing, high survival rate, straight trunk, narrow crown, excellent wood property, suitable for industrial timber.</td>
<td>timber forest</td>
<td>Beijing, Hebei, Shanxi and Shandong and Henan Province, etc.</td>
</tr>
<tr>
<td><em>P. ‘Sanmaoyang’?</em></td>
<td>Hybrid of <em>P. tomentosa</em></td>
<td>Male</td>
<td>Beijing Forestry University (BFU)</td>
<td>Fast growing, high survival rate, straight trunk, narrow crown, excellent wood property, suitable for industrial timber.</td>
<td>timber forest</td>
<td>Beijing, Hebei, Shanxi and Shandong and Henan Province, etc.</td>
</tr>
<tr>
<td><em>P. deltoides</em> cv. ‘Huanghuai3’</td>
<td><em>P. deltoides</em> ‘Bartr’ × <em>P. deltoides</em> cl. ‘10/17’</td>
<td>Female</td>
<td>Research Institute of Forestry(RIF) of the Chinese Academy of Forestry</td>
<td>For pulp- and fiber-timber plantation.</td>
<td>timber forest</td>
<td>Henan and Shandong Province, etc.</td>
</tr>
<tr>
<td>*P. × ‘Yiyang 1’, *P. × ‘Yiyang 2’, <em>P. × ‘Yiyang 3’</em></td>
<td><em>P. tomentosa</em> × <em>P. alba</em> var. <em>pyramidalis</em> × <em>P. tomentosa</em> var. <em>truncata</em></td>
<td>Male</td>
<td>Beijing Forestry University (BFU)</td>
<td>For fast-growing and high-yield plantation, shelter forest and urban greening.</td>
<td>timber forest</td>
<td>Hebei, Shandong Province, etc.</td>
</tr>
<tr>
<td><em>P. deltoides</em> cv. ‘Beiyang’</td>
<td><em>P. deltoides</em> cl. ‘Nankang1A’ × <em>P. deltoides</em> cl. ‘D175’</td>
<td>Male</td>
<td>Research Institute of Forestry(RIF) of the Chinese Academy of Forestry</td>
<td>Resistance to <em>Cerambycidae</em> and without <em>Anoplophora glabripennis</em>. For fast-growing and high-yield plantation, shelter forest and urban greening.</td>
<td>timber forest</td>
<td>Beijing, Inner-Mongolia, Shanxi, Henan Province, etc.</td>
</tr>
<tr>
<td>*P. ‘Beilinxiongzhu 1’, <em>P. ‘Beilinxiongzhu 2’</em></td>
<td><em>P. tomentosa</em> × <em>P. alba</em> var. <em>pyramidalis</em> × <em>P. tomentosa</em> var. <em>truncata</em></td>
<td>Male</td>
<td>Beijing Forestry University (BFU)</td>
<td>For fast-growing and high-yield plantation, shelter forest and urban greening.</td>
<td>timber forest</td>
<td>Hebei, Shandong and Henan Province, etc.</td>
</tr>
<tr>
<td><em>P. deltoides</em> × <em>P. nigra</em> ‘Southern Sijiyang’</td>
<td>Introduced from Pakistan</td>
<td>Male</td>
<td>Forestry Academy of Sichuan Forestry Academy of Province, Chongqing, Forestry Bureau of Xichang City, Xichang</td>
<td>High-yield plantation, semi-ever and ever green for urban greening.</td>
<td>timber forest</td>
<td>Sichuan, Chongqing, Yunan, Zhejiang Province, etc.</td>
</tr>
</tbody>
</table>
2. Production Systems and Cultivation

(a) **Nursery** practices and propagation techniques including applications of biotechnology - particularly plant propagation, reproductive materials, use of GMOs etc.

(b) **Planted Forests** with emphasis on the choice of cultivars, type of plants, spacing and layout of plantations; planting and tending (fertilization, irrigation, weeding, pruning, thinning etc.); management (growth, rotation according to yields and industrial requirements).

(c) **Indigenous Forests**, with emphasis on experiences and experiments concerning silvicultural treatments, harvesting, management, protection and regeneration.

(d) **Agroforestry and Trees** outside Forests with emphasis on their effects on forest and agricultural crops or livestock and diversification of the landscape.

2.1 Northeast Area

In the past four years (2012-2015), the researches and technical improvements in the cultivation systems of poplar plantations in Northern China have mainly been concentrated on increasing stand productivity and economic benefits through variety selection, planting density control, site preparation, fertilization, irrigation, thinning and pruning so as to develop optimum cultivation models for diversified purposes. However, more attentions have also been paid to researches on the ecological roles of poplar plantations and the maintenance of their long-term productivity, such as successive rotation and soil management, soil and environment remediation, carbon storage and fixation, etc. More than 15 research institutions have been involved in researches related to the cultivation of poplar plantations in Northern China, and the most important institutions are Chinese Academy of Forestry, Beijing Forestry University, Northeast Forestry University, Shandong Academy of Forestry, Shandong Agricultural University, Agricultural University of Hebei, Heilongjiang Province Forest and Environment Scientific Academies, Liaoning Provincial Research Institute of Poplar and Northwest A&F University.

2.1.1 Nursery practices and propagation techniques

Due to advantageous characteristics such as good wood quality, high-growth rate and easy propagation, poplar plays an irreplaceable role in the establishment of ecological and industrial forests in Northern China. To develop the optimum methods for high-quality planting seedlings production in different regions, a large number of studies and experiments have been conducted. They are mainly focused on the effects on seedling quality and field performance of various factors such as cutting density, quality, length, age, positioning, container nursery, fertilization, grafting techniques, coupling effects of water and fertilizer, seedbed seedling and pest control. To propagate *Populus × euramericana* ‘Neva’ in Hebei province of China, for instance, 1-year-old stem cuttings were better than branch cuttings of mature trees, and the optimum planting space in Hebei province was 60 cm × 90 cm, while the optimal planting density of *P. beijingensis* was 30 cm × 30 cm in Tibet (China). Considering seedling traits such as root length, root fresh weight, rooting activity, survival rate, etc, *P. deltoides* cv. ‘Zhonghuahongye’ and I-214 were the most suitable clones for container propagation.

There are many researches focused on the cultivation of poplar seedlings for specific sites (e.g. salted soils, drought and cold region) and environmental applications. These researches have investigated the effects of container type and cultivation medium on fibrous root growth and root architecture of poplar cuttings. 22 poplar clones, including *P. simonii × P. nigra*, (P. psudosimonii × P. nigra) × P. nigra CL ‘A5’ and *P. ussuriensis* were collected in Heilongjiang province. Through comparative analysis of seedling height and diameter, 5 poplar clones suitable for the Sanjiang Plain Area and 4 poplar clones suitable for the Songnen Plain Area were selected. Generally, poplar clones cannot live on sites with soil salt content above 0.2%. However, the results of hydroponics and pot experiments using 30 Aigeiros clones showed that 3 clones had high salt tolerance, and could be planted in fields with soil salt content as high as 0.5%. In addition, 6 clones could be planted in fields with 0.4% soil salt content.

Moreover, nitrogen use efficiency, water evaporation in transportation and the coupling effects of water and fertilizer have also been studied. Results showed that an increase in irrigation and nitrogen application could increase the aboveground biomass of *P. × euramericana* ’74/76’, and nitrogen fertilizer exhibited major effect on aboveground biomass. The optimal combination of irrigation amount and nitrogen rate was 35.14-41.35 kg water and 9.18-11.68 g nitrogen per tree. And other results showed that the biomass of the cuttings significantly increased after application of nitrogen and phosphorus, and the main reasons for this biomass difference were that phosphorus application markedly increased the leaf net photosynthetic rate, while nitrogen remarkably increased the total leaf area of *P. × euramericana* cv. ”74/76” cuttings.

2.1.2 Silviculture of poplar plantations

2.1.2.1 Planting density and rotation control

Planting density and rotation control are two important cultivation parameters for plantations. Generally, planting density could pose significant impacts on tree DBH (diameter at breast height) and crown size. With the decrease in planting density, the DBH and crown size significantly increased, thus the low plantation density contributes to the fast growing-rate of poplar trees. The response to weak light varied among genotypes. A plot survey was conducted in a
5-year-old poplar plantation with four different planting spacings (spacing of 2 m × 3 m, 2 m × 4 m, 2 m × 5 m, and 2 m × 6 m) to study the influence of initial spacing on tree growth and biomass accumulation. Initial planting spacing showed significant effects on DBH and single tree volume, but had no effects on tree height and stand biomass. With the increase of planting density, there was a drop in DBH, volume, crown and aboveground biomass of individual trees, while there was are rise in stand biomass. DBH and tree height were positively correlated to stem, branch and leaf biomass. Planting density of 2 × 3 m turns out to be the best choice in western areas of Shandong Province.

The effects of spacing between rows and spacing between trees in a row on growth and photosynthetic characteristics in poplar plantations were investigated in a field experiment. The experiment consisted of 3 planting patterns of 4 poplar clones (L35, I-107, W-141, zhonghe-1) under similar densities (about 417 trees ha⁻¹), and the planting spacings were 3 × 8 m, 4 × 6 m, and 5 m × 5 m, respectively. The results indicated that height and crown size of trees showed no significant correlation with planting patterns. DBH, form and individual tree volume under 5 m × 5 m planting scheme were significantly higher than that under the other schemes. Eccentricity of cross section of 5 m × 5 m allocation was lower than that in the other allocations. Pn, Tr and WUE of poplar trees increased, when planting spacing decreased. In the case of similar densities, poplars which were square planted with narrowing row spacing and poplars with increased plant spacing were more conducive to make full use of space.

2.1.2.2 Choice of poplar clones
In order to find poplar clones suitable for specific sites, a lot of studies have been conducted to select clones for major plantation in Northern China. In order to select excellent afforestation poplar species for forest systems in the oasis region of Ulan Buh sandy land, initial growth and adaptability of poplar varieties in this area were evaluated. Multi-regional trials with 60 hybrid clones of Section Airgeiros have been carried out in different ecological areas, such as Liaoning of Liaoning Province, Zhucheng, Juancheng, Ninyang and Juxian of Shandong Province, and two new pulpwod varieties (P. × euramericana cl.‘Bofeng 1’ and ‘Bofeng 2’) were selected. The mean individual volumes of clones ‘Bofeng 1’ and ‘Bofeng 2’ were 0.3487 and 0.3239 m³ respectively, at the age of 6 years in Liaoning Province, which were 23.52% and 14.73% higher than that of CK (I-108, 0.2823 m³), respectively. The new selected varieties were especially suitable for the region around the Bohai Bay in the Northeast China. About 20 poplar clones including Beikang, 08 and Zhonglin series were used as candidates and the Xinjiang Populus, which is the current main afforestation species, was taken as a reference in the researches in Ulan Buh sandy land. Among the 20 varieties, ten varieties (08-01, etc.) were able to grow vigorously and could serve as alternative tree species for afforestation and wood resources reserves in this area.

In addition, many researches also focused on the selection of clones for disease-resistance, targeted cultivation and pulp plantation. Two clones were suitable for the Yili River Valley and could be used as the raw materials for pencil industry. Similarly, the F1 generation (P. euramericana "N3016" × P. ussuriensis) was tested in Qiqihar region of Helongjiang province. The hybrids grew fast and had strong resistance against major diseases and stem-borers (e.g. grey leaf-spot, rust disease, Saperda populnea, Cryptorrhynchus lapathi). The hybrids were tree species suitable for the use as pulpwod, industrial timbers, shelterbelts and afforestation in the Northeast China.

2.1.2.3 Fertilization and irrigation
Many studies were focused on the effects of fertilization on physiological and biochemical properties, cold resistance, and water-fertilizer coupling in poplar plantations. When using the same inorganic fertilizer, application of humic acid with inorganic fertilizers could significantly increase root activity and chlorophyll content, enhance photosynthesis and water utilization efficiency, increase the contents of IAA, GA and ZT, and biomass of root, stem and leaf. According to a study on the growth of poplar in different soil conditions in Hejing County of Xinjiang, growth on sandy loam was found to be best, followed by gobi gravel soil and aeolian sandy loam. Under the same fertilization condition, adding 100 g compound fertilizer to each tree could bring the maximum growth rate. 7 kinds of different fertilizer types and 3 fertilization periods were used for P. × canadenis ‘Sacran-79’. Results showed that 200 g compound P-K fertilizer per tree could improve the cold resistance of poplar in its early stage (fast growing period). For P. tomentosa clone S86, compound N-P-K fertilizer had significant effect on promoting seedling growth, and the optimal application rates of nitrogen, phosphorus and potassium were 326.55~367.24, 175.20~201.90 and 39.24~45.81 kg/ha⁻¹, respectively. The results of other researches conducted on two-year-old poplar plantations showed that after two years of fertilization, the average tree height and DBH of the experimental group were 22% and 19% higher than that of the control group, respectively. As a fertilizer-saving and high-efficiency fertilization technique, drip fertilization has been applied in poplar plantations. A nitrogen fertilization research was conducted by Beijing Forestry University in a P. tomentosa plantation located in Gaotang county of Shandong province. Results showed that nitrogen fertilization could significantly increased tree diameter and nitrogen uptake. Furthermore, application frequency was an important management parameter of nitrogen fertilization, and 115 kg N ha⁻¹ yr⁻¹ with 4 application times per year was recommended show best results for P. tomentosa in this area.

Due to seasonal drought and low precipitation, water is the main limiting factor of poplar plantations in Northern China. There are many studies focused on irrigation techniques to increase water-use efficiency, enhance environment protection and increase potential productivity of poplar plantation. These researches covered areas such as irrigation method, irrigation
regimes, water and nitrogen dynamics within root zone and efficiency of irrigation and fertilization, etc. To develop irrigation modes that are more effective, a field experiment comparing FI (flood irrigation) and BI (border irrigation) was conducted. Results showed that compared with FI, BI showed a decreased in root biomass in the 0-20 cm soil layer by 8.28%, but in the 20-80 cm layer there was an increased of 35.87%. To evaluate the coupling effect of water and nitrogen on growth of \textit{P. × euramericana} ‘Guariento’, an experiment including nine different treatments (a combination of three irrigation treatments with three fertilization treatments) were implemented. A control plot (CK) with non-irrigation and non-fertilization treatment was also included. Results showed that fine root rates in the D2F3 and D3F3 treatments were significantly higher than that in the other treatments. Compared with CK, fine roots biomass density in the six soil layers were significantly enhanced by 359%, 388%, 328%, 3823%, 4774% and 2866%, respectively, in the treatment with high water and high nitrogen levels. For poplar plantations cultivated under drip irrigation, soil water potential could be used to indicate the timing of irrigation according to the research results of Beijing Forestry University. When planting \textit{P. tomentosa} in sites with silt soil in the North China plain, subsurface drip irrigation should be promoted in the cultivation of \textit{P. tomentosa} to improve tree growth; a range of -50 to -75 kPa at a depth of 20 cm and 10 cm distant from a drip emitter was recommended as the irrigation threshold for scheduling drip irrigation. Furthermore, irrigation should be applied between April and July, while drainage should be implemented between August and October.

2.1.2.4 Thinning and pruning

Thinning and pruning have been the important intensive cultivation techniques used to increase the productivity, wood quality, stem shape, and health level of poplar plantations. Current researches related to thinning mainly focused on the effects of thinning intensity and period on tree growth and ecophysiological characteristics, and the subsequent economic benefits. A field experiment in \textit{P. ussuriensis} plantations with four different treatments (CK: unthinned; M1: remaining tree number of 1100/hm²; M2: remaining tree number of 1600/hm²; M3: remaining tree number of 2500/hm²) was conducted to assess the impacts of thinning regimes on tree height and stock volume per unit stand area. After 3 years of thinning, compared with the CK, stock volume of M3 were significantly increased by 15.86%, while the rise of tree height was not obvious. As for \textit{P. × Liaomingensis}, a field experiment with three different treatments (CK: unthinned and remaining tree number of 556/hm²; T1: remaining tree number of 370/hm²; T2: remaining tree number of 278/hm²) was conducted. 3 years after thinning, in comparison to CK, the individual tree volume of T1 and T2 were significantly increased by 27.5% and 22.67%, respectively, while stock volume showed a slight decrease. Furthermore, an experiment was conducted to study the regulation effects of root pruning on growth of \textit{P. × euramericana} cv. Neva. Results showed that the root pruning at 8 times DBH distance significantly increased the DBH and height increments of poplar trees. The contents of N, P, K and IAA in poplar leaves as well as photosynthetic rate showed a significantly drop on the 35th day after root pruning, but increased significantly on the 161st day in comparison with the control.

The pruning researches focused on the conditions of pruned poplar stands, age, season, period and intensity, etc. The effects of different pruning intensities on growth of \textit{P. deltoides} × \textit{P. cathayana} were investigated. Results showed that using moderate intensity pruning improved DBH growth and growing stock. Composed with moderate pruning intensity, tree height and DBH in treatments under weak and severe pruning all reduced. Crown area decreased with the increase of pruning intensity. Therefore, optimal pruning intensity could not only improve the trunk crown, but also increase stand volume and improve wood quality. Using 5-year-old \textit{P. × euramericana} cv. ‘Neva’ as experimental material, the effects of different pruning seasons and intensities on the sapling growth was studied. Results showed that the treatments in which pruning the base first canopy before spring budding exhibited the best effects among all combinations. The tree height and DBH were 17.2 m and 15.2 cm, which were 24.6% and 9.4% higher than the control, respectively.

2.1.2.5. Poplar in agroforestry

Agroforestry system, in which trees and crops can make best use of environmental resources, e.g. water, nutrient, irradiance, etc, are considered to be an alternative land-use system. Poplar trees are usually planted on plat lands, which makes them the main tree species used in agroforestry systems in China. The aim of researches and practices is to establish high-efficiency agroforestry systems, which are not only focus on the utilization efficiency of resources (land, water, nutrient, irradiance, etc.), but are also interested in the economic benefits. The water use of 2-, 6-, and 15-years-old poplar-wheat intercropping systems at four growth periods of winter wheat in Yudong Plain area of Henan Province was studied by using stable carbon isotope technique. The water use efficiency (WUE) and water use quantity (WU) were calculated by using the stable carbon isotope ratio $\delta^{13}$C, biomass and meteorological data. The results showed that the $\delta^{13}$C and WUE of both poplar and wheat from all the systems showed the highest values at the jointing stages of wheat. Two-year-old poplar had the highest $\delta^{13}$C and WUE values among the three intercropping systems. The water usage of sole wheat was 25.71% less than that of 2-year-old poplar intercropped with wheat, but it was 2.78 and 1.88 times of that of 6- and 15-year-old poplar intercropped with wheat, respectively. 2-year-old poplar-wheat intercropping system had the greatest yield and highest land use efficiency.

In order to efficiently apply alfalfa in the cultivation of \textit{P. tomentosa} pulpwod plantations under the wide-and-narrow planting scheme, a field experiment was conducted to investigate the effects of mode M1 (intercropped with alfalfa), M2 (intercropped with cotton and wheat) and M3 (pure plantation) on growth and soil nutrients of \textit{P. tomentosa} pulpwod plantations in the
period of 4 years. Results showed that under M1, DBH, height, individual volume and stand volume increased on average by 6.04%, 2.53%, 13.33% and 12.07%, respectively in comparison to M2, while the same parameters increased on average by 28.18%, 26.47%, 70.00% and 10.27%, respectively, in comparison to M3. The contents of soil organic, total N and available N under M1, M2 and M3 increased to some extent in the 0-60 cm soil layer. The contents of these nutrient indicators were the least under M3. Considering the economic benefits, the total net income of M1 was the highest, which reached 78043.56 yuan/hm², which was respectively 3.97% and 38.73% higher than that of M2 and M3.

2.1.2.16 Successive rotation and soil management
As the land resource is scarce, poplar plantations can only be cultivated with successive rotation on the limited forestlands in China. The productivity of plantations follows a declining course, making the long-term soil productivity maintenance technology for plantations a hot research topic. The variety of soil nutrient environment, microbial community, fine roots structure and leaf nutrient have been the key research domains in studies focusing on the declination of forest land productivity on successive rotation plantation. Based on the Ion Exchange Resin Membranes (IERMs) and PCR-DGGE technology, the dynamics of soil nutrient pool and flux, soil microbial community were studied in poplar plantations. The results showed that the content of soil nutrient decreased over generations of poplar plantation, and the content of available nitrogen and potassium in both rhizosphere soil and bulk soil also decreased significantly. Soil nutrient deficiency was obvious in poplar plantations. The canonical correlation analysis showed that the soil nutrient availability of poplar plantation was significantly correlated to the succession of soil bacterial community. The bacterial community succession might play an important role in soil nitrification and nitrogen availability. To explore the structure and diversity of soil bacterial community, 454 pyrosequencings were applied to investigate the bacterial diversity of soil samples from rhizosphere (RS) and non-rhizosphere (NRS) in a continuous cropping poplar plantation (P. × euramericana ‘Neva’) in Shandong Province. The results indicated that continuous cropping reduced the population diversities and bacteria varieties in soil samples from both RS and NRS, with RS showing a significantly bigger drop. With the increase of generation number, the SOC and STND decreased gradually. Therefore, continuous planting for various generations should be avoided during poplar plantation management. It is recommended to take a rotation or replace tree species to avoid multiple generation effect caused by continuous cropping.

2.1.2.7 Short rotation coppice system
In a short period, short rotation poplar with high density can provide a large number of raw materials for multiple usage such as fiberboard, biomass energy, feed production and paper industry. Relevant studies about short rotation coppice systems included selection of optimal varieties, density determination, spacing configuration, biomass, chemical characteristics, forest microenvironments and photosynthetic characteristics. To select the optimal varieties for short rotation in Shandong province, a plot survey was conducted using one-year-old seeding of five poplar clones for short-rotation management. The results showed that poplar clones were a major factor influencing the biomass of one-year-old plantations, and there was a significant biomass difference among the five clones. The individual tree biomass ranged from 93.7 to 432.8 g for the five clones, among which P. × euramericana cv. ‘79-35’ had the highest biomass, followed by P. × euramericana cv. ‘74/76’, P. × euramericana cv. ‘Zhonglin46’, P. deltoites cv. ‘Zhonghe-1’ and P. × ‘Balizhuangyang’. And in Yili district of Xinjiang province, an experiment was conducted by the Forest Tree Breeding Experiment Center of Yili Prefecture in 2013. 13 varieties of poplar in local areas were used in experiments under three planting densities (2 m × 0.5 m, 3 m × 0.5 m and 2 m × 1 m). Results showed that planting density of 3 m × 0.5 m was more suitable for increasing poplar forest energy, while P. balsamifera, I-467 and I-262 were more suitable for developing forestry biomass energy. Moreover, an experiment with six planting spacings (30 cm × 30 cm, 30 cm × 40 cm, 30 cm × 50 cm, 50 cm × 40 cm, 50 cm × 50 cm, 50 cm × 80 cm) was conducted to detect the effects of initial planting spacing on growth of short-rotation poplar plantations. The results indicated that the diameter and individual biomass of P. × euramericana cv. ‘79-35’ decreased with increasing planting spacing, while the aboveground biomass increased with decreasing spacing. There was no intimate relation between the height and planting composition. Compared with the growth indexes of one-year-old poplar trees, the two-year-old poplar trees had higher levels of increase in diameter, height and individual biomass. The three-year-old poplar trees showed slighter increase in growth indexes than that of the two-year-old poplar trees.

2.2 Southern Area
In the recent four years (from 2012 to 2015), the researches and technical extensions on production systems and cultivation of poplar plantations in southern China have generally been focused on how to further improve stand productivity and increase economic benefits of the plantations through clone selection, planting density control, site preparation, fertilizing, weed control, thinning and pruning so as to develop cultivation patterns that satisfy diversified purposes. However, more attentions are paid to researches on the environmental roles of poplar plantations and maintenance of its long-term site productivity, such as the role of short rotation plantation in immobilizing CO₂ and preventing greenhouse effect, and the relationships between diversity and productivity in poplar plantations, in order to meet the requirements of social and economic development and environment protection. Approximately 10 institutions have been involved in the researches and technical extensions of poplar plantation silviculture in southern China, among
which Nanjing Forestry University, Hunan Academy of Forestry, Hubei Academy of Forestry, Anhui Academy of Forestry and Jiangsu Academy of Forestry were the most important institutions.

2.2.1 Nursery practices and propagation techniques
One advantage of poplar is that superior material is quickly available for use, because Aigeiros species used in China are easy to propagate through asexual means, usually by vegetative propagation of unrooted dormant stem cuttings. However, bareroot dormant cuttings are used to establish widely spaced plantations for agroforestry systems and plywood plantations in Southern China. In order to identify the optimum cultural practices for producing the largest number of planting seedlings of new poplar clones at each region, lots of cultural practices and studies aimed to improve seedling quality have been conducted in order to enable better matching of seedlings to forest sites and merchantable utilization, reducing the chance of regeneration delay and improving future growth of poplar plantation. Most of the researches were focused on effects of cutting density, cutting quality, hormone concentration (IAA etc.), fertilization, weed and pest control on bareroot seedling quality (morphology and physiology) and field performance (growth and survival). However, attentions were also paid to culture of poplar container seedlings for specific sites (such as salted or drought soils) and environmental application, which focused on how container type and cultivation medium affect fibrous root growth and root architecture of poplar cutting, as well as field performance in growth and survival. Moreover, effect of mycorrhiza helper Bacillus sp. on the growth of poplar seedlings was studied and the results showed that Bacillus DZ18 coinoculated with Pisolithus tinctorius or Lactarius insulsus significantly improved mycorrhizal formation rate and growth of poplar seedlings. Therefore, strain DZ18 had potential value to become an excellent bio-fertilizer strain resource.

2.2.2 Silviculture of poplar plantations

2.2.2.1 Planting density and rotation control
In order to improve the productivity of poplar plantation, some researches on planting density and rotation control were conducted. For instance, an experimental treatment applied in a split-plot design with four planting spacings (3x8 m, 5x5 m, 4.5x8 m and 6x6 m) and three poplar clones (Nanlin-95, Nanlin-895 and Nanlin-797) was established and effects of four planting spacings on stand canopy structure characteristics, understorey vegetation diversity and biomass production, and tree growth in the poplar plantations were evaluated over 8 years. The obtained results suggest that planting spacing not only significantly affect canopy structure characteristics of the plantation but also poplar plantation and understory vegetation productivity. The best option for poplar timber production at a similar site is to choose square spacing of 5x5 m. In general, the optimum harvesting period of poplar plantations in southern China within planting densities of 208-833 plant ha\(^{-1}\)is 12-13 years.

Nutrient availability and mineralization are key parameters and transformation processes that influence plant growth and forest productivity. Using ion-exchange resin method, the soil inorganic N pool (0-20 cm) was investigated in poplar plantations with different planting spacings. The external inorganic N input had a seasonal variation pattern, and the gross input of inorganic N in high density plantation was higher than that in low density during the growing season. In general, planting spacing affected N (N) availability in soil by altering N mineralization rates, while high annual N mineralization was found in soils of low density plantations, with higher rates in square spacing than rectangular spacing. Poplar plantations with different stand densities and spacing were also investigated to study the effects of stand structure on understory characteristics, and the results showed that the Shannon index of the understory was higher under the low density stands than under the high density ones, while the distribution of understory was much homogeneous under high density stands. At specific sites, choosing suitable planting spacing and poplar clone could lead to higher growth and enhanced N mineralization, but seasonal variation of soil N mineralization may not only be directly related to plantation productivity but also to understory vegetation productivity.

2.2.2.2 Choice of poplar clones and mixed tree species
According to the principle of “matching clones to right sites”, how to make full use of the achievements of poplar breeding in China and select the right clones in major poplar plantation areas is still the main task, and lots of field studies were conducted focusing on this topic. In southern China, in order to select the poplar clones most suitable to be planted on the beach land of Yangtse River, twenty clones of poplar were evaluated by improved Analytic Hierarchy Process, and clones Nanlin-895, Nanlin-324 and Nanlin-1388 were selected to plant on the beach land of Yangtse River. Microbial activity of the tree rhizosphere provides important information related to the selection of tree species for afforestation of the degraded land. Using an in situ rhizobox approach aimed to establishing a viable technique for sampling desired rhizosphere soil and assessing the feasibility of rhizosphere soil using microbial index as an indicator to screen tree species suitable for the seasonal flood land of Yantse River, China. Influences of waterlogging stress on cell structure of primary roots were also investigated to elucidate flood-tolerance mechanism of poplars, and the results indicated that normal hypertrophied lenticels, fine aerenchyma, as well as numerous structural stable mitochondria played a vital role in poplar under water logging stress. Using a rhizobox approach, a greenhouse experiment was conducted to evaluate effects of monoculture and mixed planting of three tree species on enzyme activities, microbial biomass, microbial diversity and nitrogen availability in rhizosphere and bulk.
soils. Six treatments with poplar, willow, and alder mono- or mixed seedlings grown in the rhizoboxes and both rhizosphere and bulk soils were sampled and analysed after eight-month growth. Alder addition significantly improved genotypic richness, microbial diversity index and nitrogen availability in the rhizosphere soils, suggesting that adding N-fixing alder into poplar plantations may be a good option in the practice. Compared to poplar clone monoculture, addition of other tree species obviously increased rhizosphere urease activity, but greatly reduced rhizosphere L-asparaginase activity. Poplar growth was enhanced only when coexisted with alder. These results suggested that a highly productive or keystone plant species in a community had greater influence on soil functions than the contribution of diversity. Furthermore, an incubation test was conducted to study the effects of the decomposition of poplar and alder leaf litters with different mixed ratios and under different application ways on soil microbial biomass carbon (MBC) and nitrogen (MBN). Alder leaf litter addition significantly enhanced MBC and MBN, but did not modify the ratio of MBC to MBN. Moreover, the addition of the litters did not affect soil microflora.

2.2.2.3 Fertilization and irrigation

Based on the site conditions and poplar clones, many studies have been conducted to improve poplar growth and site productivity through soil testing and formulated fertilization. Furthermore, studies are also focused on organic fertilizer application in poplar plantations. A fertilization trial on 7-year-old poplar plantation indicated that the single tree volume growth and the stand volume growth were the greatest when applying 1 kg organic fertilizer per plant, which increased 42% and 42% respectively compared with that of the contrast. Biogas slurry is a kind of high quality organic fertilizer which is rich in N, P, K, and other nutrients, the effects of pig manure biogas slurry on soil properties, soil microbial biomass carbon and nitrogen as well as growth of a poplar plantation were studied, and the results suggest that biogas slurry fertilization below 450 m² ha⁻¹ could promote poplar growth.

Fertilization affected not only poplar growth, but also the effects on soil fauna, soil respiration, and carbon metabolism. Nitrogen (N) addition significantly affected soil fauna through altering soil nutrition condition. Moderate N (10-15 g N m⁻² yr⁻¹) addition had a promoting effect on soil fauna community, while high N (30 g N m⁻² yr⁻¹) addition posed negative influence. N application influenced microbial community structure, increasing the amount of bacterial and grampositive bacterial PLFAs and decreasing the amount of arbuscular mycorrhizal fungal and protistic PLFAs. However, the annual amount of CO₂ released from the plantations of low N, moderate N and high N addition reduced by 30.3, 23.8 and 31.1% respectively. Moreover, biogas slurry application increased the concentrations of dissolved organic carbon and NO₃-N, while decreasing soil microbial biomass carbon and soil pH value, indicating that biochar improved the population of microbe that was in favor of polymer utilization and thus has the potential to modify soil microbial functional diversity.

2.2.2.4 Thinning and pruning

Thinning is one of the intensive forest management techniques commonly applied to increase the merchantable timber volume and improve the quality of the poplar plantations. Some field experiments with four or five treatments (CK: unthinned, MB: medium intensity thinning from below, HB: high intensity thinning from below, and HI: high intensity thinning by remove every alternative row of trees) was conducted to assess the impact of thinning regimes on soil available nitrogen supply, including inorganic nitrogen, DON(soil dissolved organic nitrogen) and SMBN(soil microbial biomass nitrogen), as well as restitution of litter and nutrient in Southern China. Soil available nitrogen was significantly affected by thinning treatments, and the contents of available nitrogen, DON and SMBN were the highest when treated with 50% thinning intensities. The contents of inorganic nitrogen, DON and SMBN showed a seasonal change. These results could provide a theoretical basis for the cultivation of large-diameter poplar timber.

A pruning trial of *Populus deltoides* ‘Lux’ was established and influence of initial pruning age and pruning season on wound coalescence was investigated. The full-coalescence rate of pruning wound whose width was less than 4 cm was much higher than that of pruning wound whose width was more than 4 cm. Pruning wound coalescence was influenced by initial pruning age, while the pruning wound's size was affected by branch ages. A larger number of large branches and dead branches as well as a lower rate of full-coalescence were observed as initial pruning age increased. Pruning wound coalescence was also influenced by pruning season. When branches were pruned in spring, the rate of full-coalescence and the rate of coalescence growth of pruning wound were much higher than in winter or summer. Considering the influence of pruning on DBH growth, it is suggested that the suitable initial pruning age for poplar plantation is 4 years old, and the suitable pruning season is spring(from later March to early April).

2.2.2.5 Poplar in agroforestry

Agroforestry systems are considered an alternative land-use system that increases land-use intensity and diversifies the farm economy. Agroforestry systems are widely practiced in the temperate region of China and in northern Jiangsu province, with poplar as the main tree species in this system. Researches and practices on the structural design of poplar-crop intercropping systems and its design principle for establishing high-efficiency agroforestry system were conducted. The intercropping spacing, potential productivity, resource utilization, stability and economic benefits of existing major poplar-crop intercropping patterns were summarized in various regions. Generally, the impact of different intercropping
patterns on the yield and quality of crops had strong connections with the age of poplar plantations. In order to reduce the impact of shading from the crown of poplar tree, wide spacing should be applied. Most recently, more attentions are paid to poplar-medical plant intercropping, such as poplar- amaranth (Taraxacum mongolicum) intercropping, to increase economic benefits. Agricultural non-point pollution caused by the overuse of fertilizer in farmland has become one of the main causes for water quality deterioration and eutrophication. In order to select suitable agroforestry intercropping systems to control soil nitrogen loss, different poplar-crop intercropping systems (such as poplar-wheat intercropping, poplar-amaranth intercropping etc.) were evaluated by the Nanjing Forestry University. Overall, poplar-crop intercropping systems with closer spacing (2×5 m) could significantly reduced surface runoff, leaching and nitrogen loss, while the accumulation of ammonia volatilization in the poplar-wheat intercropping systems of 2×5 m and 2×15 m spacings were 0.76-4.23 kg ha\(^{-1}\) and 2.13-4.23 kg ha\(^{-1}\) respectively, which were obviously less than that of wheat mono-cropping system. Meanwhile, the allelochemical effects of poplar root exudates on Lactuca sativa, Triticum aestivum, and Zea mays were also explored. Litter decomposition is a critical step linking ecosystem processes with plant productivity, and the effect of mixing either litter material with high N and phosphorus (P) concentrations or those with low N and P concentrations on litter decomposition and nutrient release were investigated in the context of agroforestry systems. Non-additive effects were clearly demonstrated in decomposition rates and nutrient release, when different types of litter were mixed, and such effects were moderated by site differences. Mixed species agroforestry systems can be used to enhance nutrient cycling, soil fertility, and site productivity in land-use systems.

### 2.2.2.6 Cropping system and soil management

The productivity of poplar plantation with successive rotations depleted seriously. Based on morphological and anatomical properties of the fine roots, the inter-rotation difference of fine root growth and its relation to the depletion of plantation productivity were studied to reveal mechanisms of the productivity depletion of plantation with successive rotations. Successive rotations led to significant changes of fine root morphology and significant increases of fine roots biomass, indicating that the biomass allocation to underground part was increased in poplar plantation with successive rotations. This conclusion was consistent with the theory of optimal allocation of photosynthetic products under nutrient deficiency conditions. With fine roots mortality and turnover, the allocation pattern of fine root biomass of poplar plantation with successive rotations could have a negative effect on aboveground productivity.

Polar plantation sites with different stand ages and rotations were selected to study the dynamics and the distribution characteristics of soil microbial biomass phosphorus (SMBP) and soil microbial biomass nitrogen (SMBN). The contents of SMBP and SMBN decreased with the increase of stand ages and rotations of poplar plantation. The correlation analysis indicated that there were significant correlations between SMBN and soil total nitrogen and organic matter, as well as between SMBP and the content of soil organic matter, total nitrogen and total phosphorus, but not with the soil available phosphorus. Generally, successive rotations planting of poplars should be avoided and the replacement of varieties of poplar or species could be used to alleviate the negative influence of successive planting. Meanwhile, maintaining the level of soil enzyme and microorganisms should be paid attention to, and measures should be applied to decrease the soil acidification at the same time.

### 2.7. Management modeling system and its application

Given the fact that the mixed clone afforestation mostly occurred in main planting area of southern China, a research on southern type poplar plantation management model system was carried out. By means of quantitative model method and regression technique, site quality evaluation models were established both for forested land and non-forested land, while growth and yield models for southern type poplar, including models of stand basal area at breast height, diameter distribution, diameter-height curve, stem taper, stand timber volume, stand merchantable volume and stand biomass, were developed. Meanwhile, the quantitative effect models of primary cultivation measures, database of experts’ knowledge as well as the dynamic economic benefit evaluation model were also established for southern type poplar plantations. Moreover, the relationships between optimum cultivation patterns and stand maturity ages (quantitative maturity age, technical maturity age and financial maturity age) were analyzed and described, and the model which can give optimum cultivation patterns were developed for southern type poplar plantations. Taking the Microsoft Windows XP as an operational environment and Visual C++ as tools, a computer management modeling system for southern type poplar plantations was developed. The establishment of the model system would not only provide a reliable tool for implementing the theory of modeling directive cultivation of southern type poplar, but also guide the practice of cultivation of southern type poplar plantations.

### 3. Genetics, Conservation and Improvement

#### 3.1 Biotechnology Progress in Poplar and Willow

##### 3.1.1 Genetics

##### 3.1.1.1 Application of molecular markers
In the last five years, SSRs and SNPs from candidate genes related to abiotic stress and wood properties have been developed in *Populus tomentosa* and *P. euphratica*. Also, using SRAP, AFLP, SSR, cpDNA and rDNA ITS markers, we identified genetic relationships and phylogeny of poplar clones and germplasm resources. Especially, evaluation of some population genetic structure were conducted in the native population of Tibetan poplar, *P. simonii*, *P. laurifoli, P. nigra, P. tomentosa, P. tremuloides, P. tremula* and *P. davidiana*. Using the linkage and association mapping approaches, the theories of molecular marker-assisted selection breeding were discovered in several important poplar species. New progresses include: (1) QTL analysis and dissection of SNP/SSR effects within candidate genes involved in wood formation and abiotic stress; (2) identification of additive, dominant, and epistatic variation of quantitative traits, and (3) detection of the interactions among miRNA, transcription factor and their target genes using association mapping.

### 3.1.1.2 Cyogenetics

By using the model system of *Populus*, a new strategy for characterizing hDNAs in higher plants was proposed (Dong et al., 2014a). First-division restitution (FDR), second-division restitution (SDR), and postmeiotic restitution (PMR) 2n eggs were found to be transmitted different parental heterozygosities in *Populus* using 120 triploid hybrids and 30 SSR markers. Higher poplar ploidy level can generate extensive transcriptomic diversity compared with its parents. Furthermore, recent study revealed that hybridization and polyploidization have immediate and distinct effects on the large-scale patterns of gene expression. Syntenic analysis also revealed substantial chromosome rearrangements between willow’s alternate sex chromatin.

### 3.1.1.3 Epigenetics

By using MSAP markers analysis, the associations between photosynthetic, growth traits and epigenetic diversity were examined in natural populations of *P. tomentosa*. Studies of variation in genomic methylation in natural populations of *P. simonii* revealed that epigenetics bridges environmental and genetic factors. The methylation has diverse negative regulatory roles on gene expression in poplar. Furthermore, DNA methylation also plays important roles in response to abiotic stress, such as cold and osmotic. The methylation patterns of the parents were verified to be both partially and dynamically passed onto their hybrids in *P. deltoides* and *P. tomentosa*.

### 3.1.1.4 Genomics

Subcellular relocalization and positive selection play key roles in the retention of duplicate genes of *Populus* class III peroxidase family. As our ongoing effort to understand poplar’s adaptation to salt stress, the genome sequencing of desert poplar, *P. euphratica*, has been finished and the salinity tolerant poplar database (STPD) has been established. Also, the genome of a shrub willow *S. suchowensis* has been sequenced by the Naijing Forestry University. Sequencing of the *M. brunnnea* genome provided evidence for genome-genome interactions that play an important role in poplar-pathogen co-evolution.

### 3.1.2 Genetic engineering

#### 3.1.2.1 Flowering development

Overexpression of *APIM3* regulates flowering time and floral development in *Arabidopsis*; two FT orthologs *PsFT1* and *PsFT2* from *P. simonii* can induce early flowering in *Arabidopsis* and poplar (Shenet al, 2012; Chenet al, 2015).

#### 3.1.2.2 Poplar growth and wood formation

Comparative genomics, transcriptome and proteomics analysis of a TaLEA-introduced transgenic *P. simonii* *P. nigra* dwarf mutant reveals numerous differentially expressed genes related to salt tolerance. Using transgenic operation methods, a series of studies revealed that *NACs, FLA6, Cel9A6, KOR1, PrtHB7, MAN6, REM*, and *R2R3-MYBs* can regulate cell wall thickening during fiber development in *Populus* species. Overexpression of some *WUSCHEL*-related homeobox genes are involved in adventitious root formation of poplar.

#### 3.1.2.3 Poplar abiotic and biotic stress resistance

**Resistance to drought:** Overexpression of the poplar transcription factors *NF-YB7* and *bHLH35* can confer drought tolerance and improve water-use efficiency in *Arabidopsis*; similarly, *CPK10* and *HAB1* were validated to affect drought-tolerance in *Populus*.

**Resistance to salt or cold:** Genetic operations of *XTH, CBL6, CBL10, NHX1, VP1.1*, and *DREB1* can enhance salinity-tolerance of transgenic poplar. As for studies focused on cold-tolerance, we observed that *Populus G6PDH* and *APYRASE2* can contribute to cold tolerance in model plants.

**Resistance to pest and fungal:** *Bt ‘Nanlin895’* poplar and double-*Bts P. tomentosa* were used to examine effects of *B* protein on the metabolic enzymes of pest, results showed that the activities of esterase and carboxylesterase were inhibited by *Bt* protein. Constitutive expression of *PtrLAR3* enhances fungal resistance in transgenic plants.

Also, some studies showed that (1) efficient CRISPR/Cas9-mediated targeted mutagenesis in *Populus*; (2) two different transformation vectors can provide differential expression of dual *Bt* genes in transgene poplar; (3) transient gene expression system in *Populus* was prepared from suspension cultured cells.

### 3.1.3 Molecular biology in poplar

#### 3.1.3.1 Wood formation mechanism
Using RNA-seq, we performed transcriptome-sequencing for wood tissues in *P. tomentosa*, and identified wood-related key genes and long non-coding RNAs. Furthermore, an integrated database (WFRGdb, http://me.lzu.edu.cn/woodformation/) for wood-formation related genes was reported. The *Populus TIR1* and DUF579 families revealed differential expression patterns in vascular cambium proliferation during secondary growth.

### 3.1.3.2 Flowering mechanism

Identification and expression analysis of *APETALA1* homologues and *SUPERMAN* family reveals sex-specific differences in *Populus* floral development. Transcriptome-analysis of seed hair growth in *Populus* and in the male and female shrub willows was performed and the differentially expressed genes were checked.

### 3.1.3.3 Poplar stresses resistance

**Differentially expressed non-coding RNAs and target genes:** Identification and expression analysis of different abiotic stresses-responsive and novel microRNAs were perform in *Populus tomentosa* by high-throughput sequencing. In other *Populus* species, drought-responsive lincRNAs, microRNAs and targets were detected by high-throughput sequencing and their targets were detected using degradome analysis. We obtained many DE genes of several poplar and willow species under various abiotic tolerating conditions. Some comparative transcriptioan analysis were conducted among different species, different stresses and different ploidy clones and so on.

**Key gene families affecting abiotic stresses:** Characterization, expression and molecular evolution of *AP2/EREBP* genes in poplar have been reported. Genotype-wide analysis of the Hsf and Hsp families in Poplar and Salix suchowensis reveals differential expression patterns, localization, and heat stress responses during development and abiotic stresses. In addition, several studies focused on identification and characterization of the *Populus WRKY* family and analysis of their expression in response to salt stress was conducted.

Recently, genome-wide identification and characterization of the *Populus C3HC4, CCCH, SPLs, HD-ZIP, PIN, FLAS, PP2C, 4CL, LEA, AREB/ABF*, and *ERF* gene families related to growth and development were also reported.

### 3.2 Improvement and breeding of poplar

#### 3.2.1 Aigeiros section

**Construction of the core gensemla of section Aigeiros:** the collection was set up on about 30 hm and the growth, wood property, utilization efficency of water and nutrition were accessed.

**Breeding and selection of the new varieties of section Aigeiros:** under the concept of ecological adaptation, 9 breeding regions were targeted based on their climate and the biology of poplar species, to develop new varieties for these regions. So far, more than 30 such varieties were applied for 6 regions. For instances, the new hybrid “Huanghuai 3”, “chuangxin” and “Beiyang” were used in the region along the Yangtze River. Changjiangiang river.

#### 3.2.2 Hybridization, polyploidy breeding and genetic engineering of Section Leuce

The Beijing Forestry University (BFU) produced more than 4500 hybrids from some cross combinations, including (*P. alba* L. × *P. glandulosa*) × (*P. tomentosa* × *P. bolleana*), (*P. alba* L. × *P. glandulosa*) × *P. tomentosa* Carr., and (*P. hopeiensis* Hu et Chow) × *P. bolleana* Lauche. Ploidy levels of 469 clones of *P. tomentosa* from a gene pool located at Guan County of Shandong Province were analyzed by flow cytometry. A total of 28 spontaneous triploid clones (24 female and 4 male) were found, including 2 from Beijing, 12 from Hebei, 1 from Shandong, 2 from Shanxi and 11 from Shannxi. More than 10000 seedlings from 74 half-sib families from the gene pool were collected to analyze the seed-set of different female clones. Using *P. tomentosa* clones 3119, 3532, 8212 and *P. alba* L. × *P. glandulosa* as female parent, *P. alba* L. × *P. glandulosa, P. tomentosa* ‘Shandong male’ or *P. tomentosa* ‘Baotoubai’ as male parent, a total of 746 triploid hybrids were induced by treating the pollinated female catkins in high temperature. Female gametic and zygotic chromosome doubling of *P. adenopoda* Maxim was studied and 63 triploids and 32 tetraploids were induced. In addition, the BFU selected a series of new *P. tomentosa* hybrid ‘Yiyang’ varieties, which are characterized by fast growth, straight stem and canker-resistance. They could be both used for landscaping and industrial plantation. Among the three selected clones, *P. × tomentosa* ‘Yiyang 1’ and *P. × tomentosa* ‘Yiyang 2’ were from control pollination between *P. tomentosa* ‘Truncata’ (female parent) and *P. × tomentosa* × *P. bolleana* (male parent). *P. × tomentosa* ‘Yiyang 3’ is a hybrid between *P. tomentosa* × ‘LM50’ (female parent) and *P. × tomentosa* × *P. bolleana* (male parent). *P. × tomentosa* ‘Yiyang 4’ is a hybrid between *P. tomentosa* × *P. bolleana* (female parent) and *P. alba* × *P. glandulosa* ‘84K’ (male parent). Some triploid varieties of white poplar were selected. *Populus* ‘Sanmaoyang 7’ and *Populus* ‘Sanmaoyang 8’ derived from pollination with natural 2n pollen of *P. tomentosa*, and both grow fast. *Populus* ‘Beilinxiongzhu 1’ and *Populus* ‘Beilinxiongzhu 2’ derived from *P. tomentosa* × *P. bolleana* with 60Co-ray radiated artificial 2n pollen of *P. alba* L. × *P. glandulosa*. They have good traits in growth and could be used as pulpwood. When reaching the age of five, stem volume, fiber length, and holocellulose content of these triploid clones were 79.6%, 20.7% and 1.3% higher respectively than that of the diploid control (*P. tomentosa* ‘1319’), the lignin content was 21.7% lower than that of the diploid control. In order to achieve vegetative propagation, leaf-explant regeneration system in vitro of the triploid hybrids was established.

The Hebei Agricultural University (HAU) transformed 741 poplars with double *Bt* genes and obtained 9 regenerated lines with gyromycin resistance. Toxicity evaluation on *Plagiodera versicolora* (Coleoptera) and *Hyphantria cunea* (Lepidoptera) by feeding fresh detached leaves showed double resistance. The Northwest Agriculture and Forestry University (NAFU) established fingerprinting by SSR molecular marker of 4 new hybrids of white poplar (03-4-9, 03-4-22, 03-5-17 and 03-6-11), their parents and 3 related varieties, providing the technical basis for identification of these hybrids and varieties in commercial applications.
Northwest A & F University finished interspecific cross-breeding of *Populus* in *Leuce* in 2002-2008. Nearly all native species in *Leuce* section in China were involved in cross-breeding. These are *P. alba* L., *P. alba* var. *pyramidalis* Bge., *P. canescens* (Ait.) Smith., *P. tomentosan* Carr., *P. davidiana* Dode, *P. hopeiensis* Hu et Chow, *P. adenopoda* Maxim, and one introduced clone named 84K (*P. alba* x *P. glandulosa*) from Korea. Manipulated crosses between the above-mentioned individual species in *Leuce* section were conducted. There are 34 hybridized combinations conducted and 28,000 hybrid-seedlings obtained. Seeds were sowed in container for growing at the first two months and then transplanted to nursery for growing. Selection of superior hybridized combinations and clones were carried out according to growth rate, rooting capacity and form of the one year seedlings. The nursery test showed that the hybridized combinations of *P. alba* L. x (*P. alba* x *P. glandulosa)*, *P. alba* L. x *P. tomentosan* Carr., *P. alba* L. x *P. davidiana* Dode, *P. adenopoda* Maxim. x (*P. alba* x *P. glandulosa)*, *P. hopeiensis* Hu et Chow x (*P. alba* x *P. glandulosa)*, *P. tomentosan* Carr. x (*P. alba* x *P. glandulosa)*, and *P. davidiana* Dode x (*P. alba* x *P. glandulosa*) had a high growth-rate(one-year seedling reaching 3m height). Rooting-capacity by stem cutting of the combinations with *P. alba* L. as female parent were above 80%. Through further field trials and regional tests, three superior clones named as Qinbaiyang NO.1, Qinbaiyang NO.2, and Qinbaiyang NO.3 were selected from the hybridized combinations of *P. alba* L. x (*P. alba* x *P. glandulosa*), which were characterized by fast growing rate and good rooting capacity (by stem cutting in 2015). The increase in volume of 10-year old trees was about 120-138% higher than that of *P. tomentosan* Carr. (a very famous variety for commercial use), and rooting capacity by stem cutting was about 80% higher. Now, the 3 clones of Qinbaiyang have been extended for commercial use in Northwestern regions of China. So far, some hybrids are still on the way for regional tests, we hope that 2-3 new super clones will be selected from the hybridized combinations of *P. alba* L. x *P. tomentosan* Carr., which are suitable for commercial usage in next 2-3 years.

### 3.2.3 Hybridization, polyploidy breeding and genetic engineering of Section *Tacamahaca*

The BFU produced 6317 hybrids from 117 cross combinations including *P. simonii*, *P. pseudo-simonii*, *P. nigra*, *P. deltoides* and *P. × euramericana* clones. After phenotypic investigation, general combining ability (GCA) of parents and special combining ability (SCA) of combinations were studied preliminarily. For polyploid breeding of section *Tacamahaca*, colchicine or high temperature were used to induce megaspore, embryo sac and zygotic chromosome doubling of *P. pseudo-simonii* × *P. nigra* ‘Zheyin3#’, producing 222 polyploids. Some elite triploid clones were selected to clonal test in Tongliao City (Inner Mongolia), Wuwei City (Gansu Province) and Weixian County (Hebei Province). Tetraploids were produced by anther-derived callus culture of *P. × beijingensis* W. Y. Hsu. Additionally, haploids were produced by anther culture, the frequency of haploids reached 10.3%.

Additionally, cross combination *P. deltoides* × *P. ussuriensis* produced 6 good varieties with excellent cold tolerance. *Populus* ‘Yiyang 5’ and *Populus* ‘Yiyang 6’ were produced by crossing *P. deltoides* cv. ‘Lux’ and *P. ussuriensis* cl. ‘U3’. *Populus* ‘Yiyang 7’ was obtained by pollinating *P. ussuriensis* cl. ‘U4’ with *P. deltoides* cv. ‘T66’. *Populus* ‘Yiyang 8’, *Populus* ‘Yiyang 9’ and *Populus* ‘Yiyang 10’ were all derived from *P. ussuriensis* cl. ‘U4’ × *P. deltoides* cv. ‘T26’.

The Northeast Forestry University investigated variations of growth and stress-resistance traits of transgenic *Populus simonii* × *P. nigra* clones carrying TaLEA gene. ANOVA analyses showed that growth traits, shape of stem, leaf traits, and lenticel traits between the transgenic and control poplar clones were all significantly different. Clones XL9, XL1 and XL14 were selected as suitable clones for applications owing to their high biomass and strong stability. Moreover, clone XL11 was found as a dwarf mutant characterized by small leaf, low stomatal density and leaf thickness, and thick epidermis, large palisade and spongy tissue ratios and big stomatal size. The change of growth and anatomical structure of leaf traits of the dwarf mutant may be related to the up-regulation of *AP2/PthRAV* genes. Overexpression of TaLEA gene in the transgenic poplar clones improved salt and drought tolerance, especially for the XL11 dwarf mutant, which performed the best in stress-resistance tests.

The Northwest Agriculture and Forestry University (NAFU) collected 10 clones of *P. cathayana* Rehd., *P. pseudo-simonii* and *P. przewalskii* Maxim. The cold- and drought-tolerance of several hybrids of *P. deltoides* × *P. euramericana* section *Tacamahaca* were analyzed. The order of cold tolerance of these hybrids was 07-69 × *P. cathayana* 1 > 06-57 × *P. szechuanica* 1 > 06-69 × *P. purdomii* 1 > 07-west da-zhai × *P. purdomii* 1 > 09-69 × *P. cathayana* 2 > 08-69 × *P. cathayana* 4 > E24-01; the order for drought tolerance was 07-69 × *P. cathayana* 1 > 06-57 × *P. szechuanica* 1 > 07-west da-zhai × *P. purdomii* 1 > 06-69 × *P. szechuanica* 1 > 06-69 × *P. purdomii* 1 > 06-69 × *P. cathayana* 1.

The Inner Mongolia Forestry Science Institute of Tongliao City selected 3 good hybrid varieties, including *P. × simonii* cl ‘Huilin88’, *P. simonii* × *P. nigra* cl. ‘Tonglin 7’ and *P. pseudo-cathayana* × *P. deltoides*. *P. × simonii* cl ‘Huilin88’ is a natural hybrid using *P. simonii* as female parent, with good properties including fast growth, cold- and drought-tolerance, and suitable to be planted in barren land. *P. simonii* × *P. nigra* cl. ‘Tonglin 7’ derived from control pollination of *P. simonii* with pollen of *P. nigra* L., which is characterized by easy cutting, fast growth, good cold- and drought-tolerance. *P. pseudo-cathayana* × *P. deltoides* also has some excellent traits, such as straight stem, cold- and drought-tolerance, pest- and salt-resistance.

### 3.2.4 Distant hybridization of *P. euphratica* Olive

The Liaoning Poplar Institution produced 50 distant hybrids by crossing *P. deltoides* and *P. euphratica* Olive. Variation of leaf morphology was analyzed.
The Inner Mongolia Forestry Science Institute of Tongliao City produced a good distant hybrid *P. simonii* × *P. euphratica*, which has some good properties such as easy to cutting, salt-resistance and fast-growth, which makes it suitable for landscaping and planting in saline-alkali soil.

3.3 Willows

### 3.3.1 Collection, Conservation and Utilization of Willow Germplasm Resources

The Jiangsu Academy of Forestry brought into the germplasm resources of Salix alba, *Salix nigra*, *Salix eriocephala*, *Salix purpurea* and *Salix miyabeana* in March 2013 from the Cornell University, the State University of New York and the United States Double A Willow company. Totally, 5 clones of *Salix alba*, 27 clones of *Salix nigra*, 20 clones of *Salix eriocephala*, 20 clones of *Salix purpurea*, 9 clones of *Salix miyabeana* and 3 clones of *S. alba* × *Salix matsudana*, 8 clones of “Fish Creek” were collected from united states. Now 0.6 ha nursery of willow germplasm resources from the United States were established in the Dafeng base of the Jiangsu Academy of Forestry. The survival rate and morphological parameters were recorded in November 2013.

The Jiangsu Academy of Forestry investigated and collected willow germplasm resources from Gansu province, Ningxia Hui Autonomous Region and the three northeastern provinces from 2012 to 2015. In Gansu province, 161 species seed reproduction lines were collected, among which 59 lines were artificially cultivated, mainly *Salix matsudana*, *Salix babylonica*; 102 lines were naturally distributed, mainly shrub willows. There were more than 15 collected species, including *Salix matsudana*, *Salix babylonica*, *Salix matsudana*, *Salix paraplesia* Schneid, *Salix magnifica*, *Salix jishiensis*, etc. In Ningxia Hui Autonomous Region, 8 species were collected including *Salix chelophila*, *Salix gordejevii*, *Salix permollis*, *Salix viminalis*, *Salix matsudana* and *Salix alba*. In the three northeastern provinces, 176 species seed reproduction lines were collected, among which 5 lines were artificially cultivated, mainly tree willows. More than 25 varieties were collected, including *Salix fragilis*, *Salix eriocephala*, *Salix koreensis* Anderss., *Salix viminalis*, *Salix pyrolifolia*, *Salix myrtilloides* and *Salix pterotii* Miq..

### 3.3.2 The measuring, selection and breeding of Salix clones

#### 3.3.2.1 Measuring of metal-contamination tolerance of Salix clones

**3.3.2.1.1 Measuring of Pb-contamination tolerance of Salix clones**

To evaluate the potential adaptation and remediation of Salix against heavy metal contaminations, six tree species, including *S. integra* were used in a field experiment on vegetation restoration in the abandoned lead-zinc tailings for 2 years by Zhejiang University. Plant species showed different tolerance to the tailings. Most species showed heavy metal-induced etiolation, defoliation, or growth-inhibition. There were significant differences in the increasing rates in height and base diameter, root growth, and biomass among the species. According to the evaluation, *S. integra* would be more suitable for the remediation of Pb/Zn tailings.

The Tianjin Normal University studied the effects of lead (Pb) stress on some physiological indicators of five fast-growing willow clones (*Salix ‘Zhuliu’, Salix jiangsuensis CL J-172, Salix jiangsuensis CL J-795, Salix matsudana var.anshanensis* and *Salix matsudana* Kidz) in a pot experiment. The results showed that with the increase of lead concentrations, the POD, SOD and CAT activities of the Salix ‘Zhuliu’ was the best, MDA content and chlorophyll content decreased the least, and the root activity was the strongest. It indicated that the accumulation to Pb2+ of five willows was different under the same lead concentration, and the Salix ‘Zhuliu’ was better than others. Comprehensive evaluation of each physiological parameter indicated that the lead ions tolerance order was: *S. ‘Zhuliu’ > S. matsudana var. anshanensis > S. matsudana* Koid > *S. jiangsuensis CL J-795 > S. jiangsuensis CL J-172.*

**3.3.2.1.2 Measuring of Cd-contamination tolerance of Salix clones**

The Chinese Academy of Forestry studied the effects of Cd2+ solution on morphology of the root of *S. matsudana*, *S. integra*, *S. leucopithecus* under sand culture condition. The results showed that, under Cd2+ stress, *Salix matsudana* root accelerated the absorption of calcium, and its transport to shoot. The distribution ratio of magnesium in *Salix matsudana* root significantly increased. The capacities of magnesium transport and potassium absorption of stem and leaf of *Salix matsudana* was suppressed by Cd2+ stress. Capacities of potassium absorption and potassium aboveground transport in root of *Salix matsudana* were suppressed by Cd2+ stress. The effects of Cd2+ stress on rapid light-response curves of photochemical and non-photochemical chlorophyll fluorescence quenching parameters were investigated by Mini-Imaging-PAM Chlorophyll Fluorometer. The results indicate that *S. leucopithecus* has strong tolerance to Cd2+ stress by irreversible inactivation of PS II reaction centers. However, under high concentration of Cd2+ solution for prolonged stress, PS II reaction centers were closed or irreversible inactivated, showing photoinhibition. Therefore, *S. matsudana*, *S. integra*, *S. leucopithecus* have strong tolerance to high concentration Cd2+ stress. They can be used for phytoremediation of severe cadmium polluted area, and they are good materials for breeding of willow varieties for heavy metal phytoextraction.

**3.3.2.1.3 Measuring of eutrophication polluting**
In order to analyze the tolerance of willows to eutrophication pollutions, six willow clones were irrigated by four solutions with different levels of nitrogen and phosphorous content. The results showed that there were significant differences between the growth and biomass among the different clones or TN/TP content. The sequence of the survival rate under different irrigated solution was CK>the grade of the national grade I water quality>the grade of the surface water quality of V class>the grade of the rural domestic sewage. And the sequence of the height and total dry biomass of the potted seedlings were the grade of the national grade II water quality>the grade of the surface water quality of V class>the grade of the rural domestic sewage. And the sequence of the height and total dry biomass of the potted seedlings was 7.61, which was significantly higher than others.

3.2.2 Measuring of salt tolerance of Salix clones
The Jiangsu Academy of Forestry studied 310 shrub willow hybrid clones and 32 shrub willow stock clones under 85mM NaCl stress, 6 salt-tolerant shrub willow clones were selected, including 5 shrub willow hybrid clones (2555, 2610, 35-10, 2667, 3636) and 1 shrub willow stock clone (P1024). Principal component analysis and subordinate function method were used to evaluate the salt-tolerance of shrub willow clones (2555, 2610, 35-10, 2667, 3636, P1024), the D value of 6 shrub willow clones was 0.0705, 0.1045, 0.0945, 0.0630, 0.0780, 0.0855. As a result, the order of salt-tolerance was 2610>35-10>P1024>3636>2555>2667.

3.3 Study on Molecular biology of Salix
3.3.1 The study on gene expression profiling and transcriptome
3.3.1.1 Gene expression profile in the male and female shrub willows
To gain a global view of the genes differentially expressed in the male and female shrub willows and to develop a database for further studies, the Nanjing Forestry University performed a large-scale transcriptome sequencing of flower buds which were separately collected from the two sexes. Totally, 1,201,931 high quality reads were obtained, with an average length of 389 bp and a total length of 467.96 Mb. The ESTs were assembled into 29,048 contigs, and 132,709 singletons. These unigenes were further functionally annotated by comparing their sequences to different protein- and functional-domain-databases and assigned with Gene Ontology (GO) terms. A biochemical pathway database containing 291 predicted pathways was also created based on the annotations of the unigenes. Digital expression analysis identified 806 differentially expressed genes between the male and female flower buds. And 33 of them were located on the incipient sex chromosome of Salicaceae, among which, 12 genes might be involved in plant sex determination empirically. This work provides valuable information and sequence resources for uncovering the sex determining genes and future functional genomics analysis of Salicaceae spp.

3.3.1.2 Gene expression profile of willows under Cd-stress
Using illumine paired-end sequencing, the Zhejiang University obtained approximately 60.05 million high-quality reads of willows under Cd-stress. De novo assembly yielded 80,105 unigenes with an average length of 703 bp. A total of 50,221 (63%) unigenes were further functionally annotated by comparing their sequences to different protein- and functional-domain databases. Totally 13,973 unigenes were annotated in Plant Cyc database, including 607 pathways, of which 287 unigenes were related to metal transportation and cellular detoxification, playing roles in Ascorbate-glutathione cycle, degradation of superoxide ion pathway and GSH mediated detoxification process II, etc. Based on the digital gene expression profiling sequencing, we discovered 896 differentially expressed genes in leaves of S.integra with cadmium and without cadmium, of which 293 IV were significantly up-regulated, and 603 were down-regulated under cadmium stress. Among the 293 up-regulated genes, most were annotated the hypothetical protein of Populus trichocarpa, which means that the response processes to cadmium in S.integra were controlled by many genes with unknown function. We also found several genes related to stress responses, like metallothionein (M7), metal tolerant proteins (M7P7), Zrt/Irt-like protein (ZIP), heavy metal ATPase (HAM) and phytochelatin syntheses (PC5). This work lays the foundation for further discovery of the function of these genes under cadmium stress.

3.3.1.3 The transcriptome research of Salix
The Jiangsu Academy of Forestry used 454 GS FLX platform and Titanium reagent to produce EST of the leaves of S. babylonica and S. suchowensis. A total of 547104 ESTs (280074 in S. babylonica, 267030 in S. suchowensis) with an average read length of 415 bp were generated. The ESTs of S. babylonica were assembled into 40271 Unigenes (4701Contig and 35570 Single), while the ESTs of S. suchowensis were assembled into 55083 Unigenes (7793Contig and 47290 Single). All unigenes were functionally categorized into GO (Gene Ontology) categories and metabolic pathways were analyzed into KEGG respectively. 550 differentially expressed genes were found in S. babylonica and S. suchowensis, these genes were functionally categorized into GO (Gene Ontology) categories.

3.3.2 Development of molecular markers

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RNA-seq was carried out to produce substantial expressed sequence tags (ESTs) using leaves of *S. babylonica* and *S. suchowensis* through 454 GS FLX platform by the Jiangsu Academy of Forestry. On the basis of databases, a set of SSR markers were developed, and the transferability of SSR markers of salix was analyzed between different species and hybrids. Based on transcriptome sequencing EST data resource, 4521 SSR were found in all Unigenes of salix using MISA software (1752 SSR in *S. babylonica* and 2949 SSR in *S. suchowensis*). Use the software Primer 5, a total of 1288 pairs of primers were designed (459 in *S. babylonica* and 729 in *S. suchowensis*). 1082 SSRs were successful amplified by PCR and verified by agarose gel electrophoresis (424 pairs in *S. babylonica* and 658 pairs in *S. suchowensis*). This research built a linkage map based on amplified fragment length polymorphism and simple sequence repeat using 280 F1 individuals derived from crossing of *S. erioclad*a ‘P718’ and ‘P718’. Fifty-four pairs of AFLP primers and 36 pairs of SSR primers were selected and used to construct the genetic map of *S. erioclad*a ‘P718’ × ‘P718’. 3386 makers were generated from 54 pairs of AFLP primers, including 1027 polymorphic makers. 885 makers were in accordance with Mendel’s law of segregation, and 142 makers followed partial separation. In 36 pairs of SSR primers, 17 pairs were in accordance with Mendel’s law of segregation, and 18 pairs followed partial separation.

### 3.3.3 Genetic map construction and marker-assisted breeding of willows

The Nanjing Forestry University successfully designed 106 and 90 pairs of SSR primers for chromosome XIX and XV, respectively. MAPMAKER (version 3.0) following the two-way pseudo-test cross mapping strategy was employed to perform the genetic linkage analysis, using SSR loci amplified in the present study together with 749 AFLP loci (420 were maternally informative; 329 were paternally informative).

The Chinese Academy of Forestry used 280 F1 individuals derived from a cross between *S. erioclad*a ‘P718’ and ‘P718’ as materials. 902 markers in accordance with Mendel’s law were generated for construction of genetic linkage map using JoinMap4.0 software. 19 major linkage groups, 2 small linkage group, 7 triplets and 16 doublers were obtained. 609 AFLP markers and 8 SSR markers were ordered to the 19 major linkage groups. The distance of linkage groups was between 47.32 cM and 225.30 cM. The total distance of linkage groups was 2481.75 cM, and the average distance was 4.07 cM. Estimated length of genetic map was 2208.35 cM. Map coverage rate was calculated according to the method of Lange (1982) and Bishop (1983), which was 99.29% and 99.98%, respectively.

### 3.3.4 Cloning and expression of salt-tolerant genes

The Jiangsu Academy of Agricultural Sciences cloned salt tolerant genes from salix using the primers designed according to the genes of *P. trchocarpa*. The open complete reading frames of betaine aldehyde dehydrogenase (BADH) gene and VHA-B gene were cloned from salt tolerant Salix cultivar L0911. Their length were 1539 bp and 1566bp, respectively, and coding 512 and 518 amino acids (aa), respectively.  Real-time fluorescence quantitative PCR revealed that gene expression of Salix cultivar L0911 could be induced by NaCl stress, indicating that BADH VHA-B genes were related to salt stress.

### 3.3.5 Research of Salix diseases and pests

The Jiangsu Academy of Forestry released *Dastarcus helophoroides* on willow trees in some parks of Nanjing City in order to to parasitize on and control *Anoplophora glabripennis*, which severely harmed the willow trees. The parasitic rate and control effect were periodically determined. The results showed that the release of *Dastarcus helophoroides* could effectively control *Anoplophora glabripennis* both in the first and second year. The corrected parasitic rate of *Dastarcus helophoroides* could reach 35% one month after releasing, and the corrected decline rate of *Anoplophora glabripennis* pest population was about 45%. The average parasitic rate of *Dastarcus helophoroides* on *Anoplophora glabripennis* was around 37% in the second year. The study showed that *Dastarcus helophoroides* could parasitize on pupa of both *Anoplophora glabripennis* (with a parasitic rate of 67%) and *Zophobas morio* (with a parasitic rate of 85%), while it could not parasitize on *Bombyx mori* pupa.

### 4. Forest Protection

#### 4.1 Poplar Insect Pests

Generally speaking, the situation of insect pests damage of poplar and willow species during the past five years tends to be steady. However the following states could be summarized: (1) In the three northern regions, especially in Gan-su and Shan-xi Province, the Asian Longhorned Beetle (*Anoplophora glabripennis* (Motschulsky)) has reappeared, damaging ecological protection forests since its last severe outbreak almost 30 years ago. (2) *Saperda populnea* L. was found to destructively harm poplar trees in cultivation lands in Tibet, some 2-year-old seedlings were completely destroyed. (3) Local defoliator pests seriously occurred in some regions, such as He-nan, Shan-dong and Jiang-su Province. Invasive defoliator pest-*Hyphantria cunea* (Drury) is rapidly spreading to new regions, bringing severe damages. Jiang-su and An-hui Province have become its new colonization. (4) The spreading risk of *Xylotrechus rusticus* L. was analyzed and predicted as follow: the high-adaptive area is northern, northwestern, southwestern China, and most parts of northeastern China; the moderately adaptive area is Fujian, Zhejiang and Jiangxi province, most part of Jiangsu, Anhui, Hubei and Guangdong province, the northern part of northeastern China, the southeastern part of Henan province, and the central part of Ejina County.
4.1 Basic Researches on Insect Pests

During the past 5 years, insect pests damaging poplar and willow trees mainly included Coleoptera, Lepidoptera, Hymenoptera, Homoptera, Hemiptera and Orthoptera. Among them, the most widely studied defoliators are including: Apocheima cinerarius Ersschoff, Clostera anachoreta Fabricius, Micromelalopa troglodyte Graeser, Leucoptera susinella Herrich-Schaffer, Hyphantria cunea Dray and Stilpnootia candida Staudinger etc. The bio-ecology characteristics and occurrence pattern of A. cinerarius were detailedly investigated, providing essential information to monitor and control this pest. The bio-ecology characteristics, especially the life history, growth period and copulation behaviors of C. anachoreta, M. troglodyte and Chrysomela populi L. were investigated. Host preferences of L. susinella were studied; results showed a decrease in host preference in the following order: P. beiingensis W. Y. Hsu, P. alba var. pyramidalis Bunge, P. nigra var. italicana (Moench) Koehne. Host preferences, starving tolerance, cold tolerance of H. cunea (Dray) fed on poplar trees were also investigated.

Researches showed that woodbokers damaging poplar trees mainly included: Anoplophora glabripennis (Motschulskey), Xylotrechus rusticus (Linnaeus), Saperda carcharias (Linnaeus), Saperda populnea (Linnaeus); Apriona germani (Hope), Batocera horsfieldi (Hope), Cryptorrhynchus lapathi (Linnaeus), Melanophilapicta Pallas, Pocelionota variolosa (Paykull), belonging to Coleoptera; and Paranthrene tabaniformis (Rottenberg), Cossuscus orientalis Gaede belonging to Lepidoptera. Most of the studies focused on the outbreaks of the pests, pest occurrence pattern, damage characteristics and bio-ecology characteristics such as host preferences, flight ability, sensilla morphology characteristics etc. X. rusticus was one of the most widely studied pests. Long Pan et al. (2015) measured the frequency distribution of the head capsule and the pronotum width, and determined that each larva has 13 instars. Jue-Wen Li et al. (2013) re-constructed three dimensional gallery features to illustrate different damage stages of X. rusticus, in order to provide guidance in monitoring and detection of this pest. Ling Li et al. (2014) investigated the associated fungi-Fusarium solani (Mart.) Sacc. of X. rusticus. Ling Li et al. (2013) studied the influence of electroantennogram and behavior of X. rusticus from the bark essential oils of its hosts, and found that it attracted benzothiazole. Besides, host preference and breed resistance of poplar were also investigated, for example, resistance of different poplar strains against C. lapathi were tested. Furthermore, relationships between the resistance level of poplar strains to C. lapathi and the physical properties of poplar trunks were studied. In the breeding of highly resistant strains to C. lapathi, it is recommendable to choose P. pseudo-simonii, P. cathayana or P. suaveolens as parents, while P. deltoides or P. nigra should not be chosen as parents.

On the plant-insect community aspect, Zhang (2012) investigated the resources of moths in three poplar samples in Nanjing Xiaozhuang College, the results showed 69 species belonging to 62 genera, 13 families, and the diversity of moth in different seasons showed that the main factor was obviously seasonal variation. Yan (2013) investigated underground pests in Anhui Province, the results showed that the grubs were composed of 9 species in 3 families, and the dominant species were Holotrichiapa rallela, Maladera ovatula and Serica orientalis. Wu (2014) investigated the community structure of pure poplar- and mixed forests in Jinhshatan. The number of families, species and individuals of insect community was the following order: poplar pure forest < poplar and scotch pine mixed forest<poplar, scotch pine and buckthorn mixed forest< Poplar, scotchpine, buckthorn, and caragana mixed forest.

4.1.2 Induced Resistance and Physiological Changes by Insect Pests

Induced resistance is a defense system within plants which allows them to resist pest attacks. The defense system reacts to the external attacks with physiological changes, triggered by the generation of proteins and chemicals that lead to activation of the plant's immune system. Understanding this physiological proces will lead to improvements in eco-friendly pest control methods.

Wen Zhang (2006) studied the role of hydrogen peroxide (HP) in interplant wounding signal transduction of P. simonii x P. pyramidalis ‘opera 8277’. The contents of HP appeared to increase in the Clostera anachoreta herbivore-infested leaves and undamaged parts of herbivore-infested leaves, but also increased in the neighbouring healthy plants. The antioxidant enzymes were also activated; and Jasmonate-signal transduction pathway was also involved in the induction of plant defense. Besides, the differential expressions of defense-related genes and oxidative burst were induced by C. anachoreta wounding. The functions of H2O2, Jasmonic acid and abscisic acid in defense respond, the emission of aldehydes induced by mechanical damage, the effective airborne signal molecules between poplar plants were also investigated. Yan Wang (2009) investigated the variation of foliar phenolic compounds in P. euphratica under environmental damage in Ejina Oasi. Furthermore, the chemical structure and their important roles in defense against insect damage and environmental-stress-resistance were summarized. The defense responses of poplar strains induced byS. populnea were studied to select the more insect-resistant poplar strains. The nutrition and secondary metabolites were compared before and after damage caused by S. populnea. Hui-Fang Yue (2013), Yu-Tong Wang (2015) investigated the resistance induced by exogenous jasmonic acid in P. cathayana and the effects of the gypsy moth, Lymantriadispar on development. Contents of peroxidase (POD), polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), chymotrypsin inhibitor (CI) and trypsin inhibitor (TI) increased accordingly. The weight of L. dispar decreased, while the developmental duration increased after feeding with treated poplar leaves. The roots of most land vascular plants can form a symbiotic association.
(mycorrhiza) with special fungi. The development and growth of *C. anachoreta* mediated by ectomycorrhizal fungus *Paxillisis involutus* inoculated on *P. × canescens* was investigated to support the hypothesis. The results showed that the inoculated *P. × canescens* with *P. involutus* could reduce the development of *C. anachoreta* larvae by changing the total nitrogen, phosphorus, soluble sugar, protein, starch, and hormones contents.

In the recent 5 years, the physiological index changes of poplar damaged by pests have been only occasionally reported. Liang (2012) investigated the characteristics of photosynthesis of damaged poplar leaves and discussed the photosynthesis compensation of poplar after feeding with larvae of *Micromelalophoa troglodyte* and proved that poplar had developed an adaptive mechanism of photosynthesis compensation in response to the damage (Jun-Sheng Liang et al., 2012). LI (2015) investigated potential effects of artificial defoliations at 0%, 25%, 50% and 75% levels to imitate the defoliator-caused damages on biomass and chlorophyll content in poplar (*P. simonii × P. nigra*) 5, 10, 15, 20 and 25 days after each treatment. The results showed that defoliations pose significant impacts on carbon sequestration and photosynthetic physiological responses of both poplar and larch seedlings.

### 4.1.3 Insect-Resistant Transgenic Poplar and Insect-Resistant Poplar Varieties

The study on insect-resistance of transgenic poplars was mainly focused on transport of two types of Bt genes (BtCry3A and BtCry1A), whether the pattern was one by one or both at the same time. A study on *Hyphantria cunea*, found that transgenic poplar 741 still had a stable resistance to *H. cunea*, which could be concluded through the decrease on activities of the midgut proteases and retardation of the growth of the larvae. Transgenic hybrid Europe and American black poplar showed that deratization rate of *Hyphantria* instar larvae obviously increased. BtCry3A and BtCry1A double-transgenic poplars were fed to *H. cunea* and *Plagiodyera versicolora*, results showed that the double Bt -transgenic 741 poplar was Lepidopteran pests - and Coleoptera pest-resistant, widening the insect-resistance spectrum. For *Aprionagermari*, all 6 strains of Bt Cry3A-transgenic poplar showed certain inhibitory effect in terms of oviposition of adult and growth of the larva of *A. germari*. For *Clostera anachoreta*, which were fed with leaves of Bt Nanlin 895 poplar, we found that the transgenic poplar inhibited the activities of esterase and carboxylesterase, disturbed the protection enzyme system and had an insecticidal effect of the larvae. Under the same Bt-concentrations, the *C. anachoreta* experimental population’s mortality decreased with growth, i.e. the Bt-resistance in pests increased with age. Under different Bt concentrations, *C. anachoreta* experimental population’s mortality increased with Bt concentrations. For scion’s insect-resistance, studies showed that scions from transgenic plants which were grafted onto non-transgenic plants maintained high insect-resistance, while scions from non-transgenic plants which were grafted onto transgenic plants became to a certain degree insect-resistant too. For populations, transgenic poplars have changed Arthropod population and community structure, and the diversity of the insect community has been increased. Two kinds of transgenic poplars restrained target pests, avoiding pest eruption. And the temporal dynamic trend of the arthropods community was the same in the two kinds of transgenic poplars and non-transgenic poplar. A study on the ecosystems of cotton-poplar intercrops found that intercrops containing transgenic poplar significantly increased the inhibitory effects of Bt-transgenic cotton on Fall web worm moth. Analysis on insect-resistance of species or strains found that poplar strains with high resistance to *Criptorrhynchus lapathi* was Leuche and its hybridism, the native tree *P. maximoviczii*, while *P. nigra* and its hybrid mand Tacamahaca were highly cold-resistant. Poplar strains high resistant to *Panarthrene tabaniformis* was Zhungeer NO.1-20, Zhungeer NO.3, Nanlin106-Nanlin105, NO.96 poplar K15 and triploid Chinese white poplar.

Different varieties of poplar species show different levels of resistance to certain insect species. Feng-Yan Wang, et al. (2011) investigated the survival condition of eggs and larvae of *A. germariin* in 12 varieties of poplars using cage inoculation, results showed that *P. deltoides* cl. ‘Sangiu’ was the most resistant, *P. nigra* and *P. × deltoides* cv. ‘74 /76’ came after, *P. deltoides* cv ‘Nanyang’ was the least resistant. Jian-Jun Hu, et al. (2013) cultivated *P. deltoides* “Nanyang”, which had high resistance to *A. glaberipennis* and moderate resistance to *A. germari*. In addition, Hu (2014) cultivated *P. deltoides* ‘Zhongcheng1’ and ‘Zhongyul’ which have high resistance. Fu-Sen Wang, et al. (2014) found that *P. euramericana* “N3016” × *P. ussuriensis* had stronger resistance to the main boring beetles (*S. populnea, Paranthrene tabaniformis* and *Siricidae* species). Zhi-Guo Ding, et al. (2014) found that Triploid Chinese white poplar and *P. adenopoda* were resistant to *Batocera lineolate*. The attacking rate increased first and decreased afterwards with the increase of tree ages, 5to15-year-old poplars were more seriously damaged. Injury rate also increased first and decreased afterwards with the increase in tree height, and peaked at the height of 8-14 meters. Injury rate topped at DBH of 5-11 centimeters, and decreased afterwards with the increase of DBH. Mixed forests were less damaged by *B. lineolata* than the pure forests. The more abundant the food source was, the more serious the damages to poplars were. The effect of different poplar varieties on population of *Hyphantria cunea* was evaluated, their resistance from high to low was as follows: *P. ×euramericana* ‘L35’, *P. ×euramericana* (Dode) Guiner cl. ‘Zhonglin 46’, *P. ×euramericana-W141, P. ×euramericana Carppacio, P. deltoides ‘L323’, P. deltoides ‘PE-19-66’, *P. ×euramericana* ‘Guariante’ L35 and W141 were the optimal varieties for the control of *H. cunea*. Qing-Jie Cao & De-Fu Chi (2015) carried out a study to find out the relationship between the resistance level of poplar strains to *Osier weevil* and the physical properties of their trunks. The
results showed that the harder the phloem and xylem of poplar strains were, the higher their resistance level to Osier weevil was, and laid foundation for the breeding of highly resistant strains to Osier weevil.

4.1.4 Pest risk analysis
During the last 5 years, only a few researches in China were focused on the risk analysis of pests damaging poplar and willow trees. However, the importance to predict and monitor the occurrence and development of insect pests is obvious. The risk of Melanophila decaestigmain invading Xin Jiang province was analyzed by Nuerguliet et al. (2013), results proved that it a high risk insect pest. The risk of Cryptorrhynchus lapathi invading Qing Hai Province was analyzed, it was also a high risk pest with the trend of spreading all over Qing-Hai Province. Jue-Wen Li (2014) investigated the tolerance to extreme low and high temperatures and the relevant physiological variation of Xylotrechus rusticus, and analyzed the spreading risks of this long horned beetle. The results showed that the high-adaptive areas were northern, northwestern, southwestern China, and most part of northeastern China. The moderately-adaptive areas were Fujian, Zhejiang and Jiangxi province, most part of Jiangsu, Anhui, Hubei and Guangdong province, northern part of northeastern China, southeastern part of Henan province, and central part of Ejina County.

4.1.5 Control
In the past 5 years, numbers of new control methods, pesticides, and natural enemies have been developed to control the insect pests damaging poplar and willow trees. Xi-Ping Niu, et al. (2015) indicated that both the nymphs and female adults of Drosichacorpulenta (Kuwana) displayed obvious taxis responses to the volatile of host plants Diospyroskaki, Ziziphus jujube and P. tomentosa, and provided a potential inter-cropping pattern of Zanthoxylum bungeanum and Ailanthus altissmato to achieve biological control of D. corpulenta. Yun-Peng Liu, et al. (2012) suggested that Lambda-cyhalothrin and Acetamiprid could be considered as the first selected pesticides to control D. corpulenta. To control Micromelalopha troglodyte, Closteria anachoreta and Botyodes diniasalis, the best control effects could be achieved by spraying 1:600 dilution of martinine-miotic missible oil with 1.2% potency. Yuan-Yuan Li, et al. (2014) proved Methyl jasmonate as an inducer can enhance defensive responses (resistance) of poplar against defoliators. However, it can also weaken the carbon sequestration capacity of poplars. Feng-Yan Wang, et al. (2011) investigated the lethal effects of 5 pesticides on Aprionagernari with the soil spraying method, results showed that imidacloprid and Actara were effective.

Considering natural enemy, Yue Gao, et al. (2013) conducted a field experiment releasing Trichogramma dendrolimi in poplar plantations to study the control of Notodontidae's eggs in P. ×euramericana. Chao-Yang Yue, et al. (2013) found that the average control effect of releasing Dastarcusleleporoides adults in the forest and border trees reached 63.82% and 76.85%, respectively, while the average control effect of releasing of D. helophoroides eggs was 65.88% and 67.42%, respectively. Hamili et al. (2013) selected four parasit species to control the larvae of Saperdarcharias in laboratory, the control efficiency ranking from high to low was as follows: D. helophoroides>Sclerodermus pupariae>S. sp.1= S. sp.2.

4.2 Poplar Diseases
4.2.1 Basic Research
The type III secretion system (T3SS) cluster was identified in the poplar canker pathogen Lonsdalea quercina N-5-1 genome. The 23 kb T3SS included 26 genes, 9 of which were highly conserved hrc genes. T3SS hrc V mutant and complemented mutant HBhrc V were inoculated on P. × euramericana ‘Zhonglin 46’. The Δhrc V was less virulent, while the HBhrc V virulence to the wild-type strain. The hrc V mutation abolished the HR, but did not influence growth, motility, and biofilm formation, suggesting that the T3SS is an essential pathogenic factor. The hrcJ was introduced into N-5-1 by vector pEXI8Km-hrcJ. The hrcJ mutants were screened and verified by PCR and Southern blot. P. ×euramericana cv. ‘74/76’ was inoculated, with wild-type, the hrc J mutant, and the complemented HBhrc J mutant. The hrcJ mutant was less virulent. Growth capacity of hrc J mutant had no significant change compared with wild-type, and the ability of biofilm formation showed that the motility of hrc J mutant decreased 21%. The cultivable bacteria and fungi from healthy and diseased P. ×euroamericana in Puyang, Henan, China show that the dominant fungi are Alternaria alternate and Fusarium solani, respectively. And the dominant bacterial is L. quercina. Furthermore, F. solania and L. quercina became the preponderant species.

P. tomentosa H₂O₂ content was higher than P. ×beijingensis at the early stage of Botryosphaeria dothidea inoculation. After 72h, H₂O₂ content reached its maximum (737.52 mol/g) and a large number of H₂O₂ CeCl₃ appeared. After B. dothidea inoculation, APX and POD of P. tomentosa were higher than that of P. ×beijingensis. H₂O₂, APX and POD were related to resistance. Twelve poplar housekeeping genes and 9 poplar plasma membrane intrinsic protein (PIP) genes were detected by RT-qPCR in P. beijingensis infected with B. dothidea. The expression patterns responding to fungal and drought was different, and the water transportation mechanisms were different too. Five PIP genes in drought-pathogen interaction were higher expressed than in drought or pathogen alone. Solexa cDNAs sequencing of control and B. dothidea treated conditions resulted in a total of 339,283 transcripts and 183,881 unigenes. A total of 206,586 transcripts were differentially expressed. There was significant accumulation of energy metabolism- and redox reaction-related-macromolecules according to GO and KEGG.
enrichment. A total of 852 transcripts (575 up and 277 down) were involved in plant–pathogen interaction, signal transduction, defense, and cofactors. Moreover, GST reached high levels, revealing key genes and proteins potentially related to pathogen resistance. RT-qPCR validation revealed highly reliability. The unsequences, from B. dothidea inoculated P. tomentosa cDNA library, were selected and analyzed by RT-qPCR. Randomly selected 199 positive clones were sequenced, and 172 EST homologous were found. Ten defense transcription associated sequences were divided into 4 categories, i.e. Zinc finger protein, CONSTANS-like protein, transcription factor (TF), and WRKY21. RT-qPCR showed that the expression of these 3TF significantly increased. Poplar infected with Dothiorella gregaria and control were analyzed by GC-MS. A total of 4,051 features were detected and 44 significantly changed metabolites. Metabolism pathways and networks were constructed.

The pathogenicity of 64 Cytospora chrysosperma strains, isolated from 31 cities of 11 provinces in China, did not related to the geographical origin, while it showed relevance to host species. The strains isolated from poplar showed stronger pathogenicity than that from non-poplar hosts. The study indicated an obvious relationship between the geographical origin and the genetic diversity grouping. CHH001 isolated from P. alba × P. berolinensis was identified as C. chrysosperma by morphology and ITS-PCR. RT-qPCR indicated poplar ZFP1 and 69-IV-2-4 had higher levels of relative expression. ZFP1 may participate in plant-pathogen recognition and defense. Northeast China102 Cytospora were divided into five morphological groups based on locules, discs, conceptacles, conidia of anamorphs and associated teleomorphs, and cultural characteristics. The classification of the 5 groups were well supported by the ITS phylogenetic.

4.2.2 Disease Diagnosis and Identification

A Gram-stain negative, Neisser-stain negative, aerobic, non-motile, non-spore-forming, slimy, glossy bacterial strain with single or clustered cocccid cells and white colony color, designated as 2-bin7, was isolated from cankered P. ×euramericana from Qingfeng, Puyang, Henan, China. Strain 2-bin7 is a novel species, for which the name L. puyangensis sp. nov. is proposed.

Five Tylenchida and 2 Dorylaimida nematodes were identified from poplar rhizosphere soil in 54 different sites from Zhenjiang and Jiangsu province. These species included Filenchus orbus, F. vulgaris, Tylenchorhynchus brassicae, Helicotylenchus digitiormis, Scutellonema brachyurum, Xiphinema X. americanum and X. huniense. F. vulgaris was a new record in Jiangsu, and the poplar was the new host of F. vulgaris, T. brassicae and X. huniense.

Poplar powdery mildew in Jiangsu, and the disease in Harbin was done and was identified as Fusichadium tremulae (Fr.) .Canker fungus of P. ×euramericana CL ‘74/76’ was identified as Apiocarpella macrospora, which was reported for the first time and was also a new disease on poplar in China.

4.3 Disease Resistance

SA and hydrogen peroxide H2O2 were analyzed in P. tomentosa and P. × beijingensis inoculated with B. dothidea. Poplar resistance was relevant to the accumulation of SA and H2O2. After M. larici-populina –infection of poplar clones with different levels of M. larici-populina-resistance , PPO, PAL, chitinase and β-N-Acetyl -D-glucoaminidase enzymatic activities were all higher than the control. The fat soluble differences are significant in the poplar buds with different levels of anti-rust resistances. The buds of N195 and N177 contained α-Caryophyllene, α-Bisabolol, and methylarachidate. Cinnamic acid, 4-Cyanophenyl-propylbenzoate, 9-Phenanthrol, retinaldehyde, chlorodiphenylmethane, and p-Hydroxy-cinnamic acid only existed in N195, while α-cadinol, 2-phenethyl octanoate, 9-Aminoacridine, and 1-Docosanol only existed in N177.

Experiments on P. deltoides-resistance to rust showed that the seedling height of 6 families was in normal distribution, whereas the basal diameter was concentrated within 5-9 mm. There were significant differences both in height and basal diameter. The ZS8×2-33 was more susceptible, while the 2×2×2-9 was highly resistant. Urediospores of M. larici-populina spread from August to early November, the urediospores spread the most in the mountainous region at mid-September and in plain regions at mid-October. This disease occurred in the west of Guanzhong, and spread from west to east, from low to high altitude, from high to low altitude and from the mountainous to the plain areas.
The Lonsdalea disease indexes of *P. xeuramericana* cv. ‘Zhonglin 46’ were higher than that of ‘74/76’. The canker had a significant correlation with accumulated temperature, daily average temperature, maximum temperature, minimum temperature, relative humidity and wind speed. RT-qPCR detect SA and JA showed that in resistant *Lonsdalea quercina* subsp. *populi*, the expression of *PR1-1*, *PR1-2*, *NPR1-1*, *NPR1-2*, *TGA1*, *TGA2*, *MYC2-1*and *MYC2-2* was higher in *P. tomentosa* than susceptible *P. deltoids* cv. ‘Zhonghe 1’. While, *JAZ1*, *COI1-1* and *COI1-2* were expressed lower. It suggested that the canker resistance induces the SA and JA signal transduction. *P. tomentosa* inoculated with *Rhizoctonia solani* Rs-1 after Endophytic *Chaeatomium globosum* ND35 inhibited pathogenic expanding, but significantly increased the activity of POD, PPO and PAL. The 3 defense enzymes were induced by ND35 and enhanced resistance. When inoculated with canker, the *BG2* transformed *P. xeuramericana* cv. ‘Neva’, T-107, grew better than the C-107. The T-107 MDA levels were lower than C-107. Although both increased firstly and then decreased, the PAL content of T-107 was always higher than C-107. After 15 d, all C-107 were dead, but T-107 were still alive, indicating that the *BG2* improved resistance. The meteorological suitability index was divided into 4 grades of very suitable, suitable, basic suitable, not suitable, which could reflect the suitable degree of meteorological condition for occurrence and development of *Valsa sordida* Nits.

### 4.2.4 Control

Twenty four out of 115 strains could inhibit mycelium growth of poplar canker *B. dothidea*, among which 5 strains were selected for good control effect on poplar canker, and the strain YGF9 was determined as the most effective antagonist of *B. dothidea*. It was found that the two biocontrol strains, *Trichoderma aureoviride* YGF9, and *Fusarium equiseti* LX6F2, could produce antagonism enzymes and inhibit pathogen’s growth.

Characteristics of β–glucanase produced by *Bacillus velezensis* YB15 showed that the strainplayed antagonistic roles against many pathogenic fungi. Width of inhibition zone against *Helicobasidium purpureum* was 11.0 and 10.6 mm by YB15. The YB15 β–glucanase genenames *Bglu1* was 732bp and encoded 243 aminoacids.

A chitinase gene (*Bbchit1*) from *Beauveria bassiana* was introduced into *P. tomentosa* which over expressed LAR3. *Bbchit1* and LAR3 were detected in transgenic plants by real-time PCR. The transgenic poplar plants displayed a significant reduction in their disease symptoms after they were infected with *Alternaria alternate*.

Bacteriostatic activity of *Inonotus obliquus* products had inhibitory effects on 7 pathogenic bacteria, and the highest inhibition rate of *B. larinica* and *C. chrysosperma* was discovered to be after 23 days. Alcohol extracts contained the main antibiotic active substance. *Bacillus pumilus* JK-SX001antifungal substances on poplar canker pathogen *C. chrysosperma*, *Phomopsis macrosora* and *Fusicoccum aesculi* were used. The non-protein antifungal substances and inhibitstomycelia and germinated-spores were studied while physical and chemical properties were measured. Thenon-protein antifungal substances had a strong inhibitional effect on mycelia growth and spore germination, and could dissolve the spore. Ethanol conidial extracts of *T. harzianum* against *C. chrysosperma* showed the highest inhibition rate. There was significant difference between different treatments. Antibacterial substances from *Phellinus linteus* were used on 7 pathogenic bacteria. The highest inhibitory rate was appeared on20 days treatment. The ethyl acetate extracts *T. virens* T43 reduced *C. chrysosperma* enzymes activities, the soluble sugar and protein contents, with SOD activity also decreasing. However, it increased the MDA content in pathogens, and hence destroyed cell integrity. The extracts *Trichoderma* T-33, T-14, T-09 from 29 domestics inhibited *C. chrysosperma* mycelium growth and conidia germination. Phylogenies of 18S r DNA showed that T-33 was *T. viride*. From *Populus*, 23 out of 56 strains belonged to endophytic antagonist bacteria. Resistance against *C. chrysosperma* showed that Y-S-Y12 had the most significant effect, followed by Y-S-Y2. Y-S-Y12 was *Bacillus amyloliquefaciens* according to 16S r DNA. It was found that 10% difenoconazole water dispersant, 250g/L azoxystrobin suspending agent, 70% thiophanate methyl wettable powder showed high virulence to *C. chrysosperma* and *Dothiorella gregaria*.

Eight fungicides used against poplar powdery mildew showed that the control effect of carbandazin 50% WP, be diluted 600 times, was 72. 25%. Trichloroisoanuric acid SP (85%), azoxystrobin SC (40%), acetic acid bacteria amine salt AS (1.8%), asomat WP (40%) could control *Melampsora larici-populina* effectively. Humic acid copper and thiophanate-methyl asomat showed higher control ability against the *Cytospora* of *P. tomentosa* canker. Carbendazol wettable powder and thiophanate-methyl asomat had better control effect to *Dothiorella gregaria* Sacc. canker.

### 5. Harvesting and Utilization

#### 5.1 Processing and Utilization of Poplar

##### 5.1.1 Study of Poplar wood properties

It has been found that the normal wood and tension wood of *P. xeuramericana* cv. ‘Neva’ should be treated differently in processing and utilization because of the different chemical composition, fibre morphology and pulping and papermaking properties (*Zhou et al.*, 2012). The chemical composition, physical and mechanical properties are significantly different between transgenic and non-transgenic *P. alba* (P. davidiana +P. simonii) ×P. *tomentosa* (*Zhang et al.*, 2014; 2015). The physical and mechanical properties of 11 clones of *Populus deltoides* were compared, and there were significant linear
correlations between them except the impact toughness (Pan et al., 2014). And Wang et al. (2015) found that there were no obvious differences between the normal fiber and gelatinous fiber of *Populus deltoides* normal wood.

5.1.2 Reinforcing Modification of Poplar Wood

5.1.2.1 Compression and Densification of Poplar Wood

The poplar *P. euramericana* veneers have been compressed under mechanical pressure, and fixed to avoid deformation by high temperature heat treatment (Chen et al., 2013). Transverse compression method was used in poplar wood densification treatment, and the properties of the treated wood under optimization process were better than oak wood (Chen et al., 2012). Wang et al. (2012) and Xia et al. (2013) studied the surface densification and fixation technology of Chinese white poplar wood under the control of water and heat. They found that the treated wood surface density and hardness could reached 0.92 g/cm³ and 22.3 N/mm², which were 1.8-2.1 times and 2.4 times of that of the control samples, respectively. Moreover, when the compressed wood were treated under 180°C for 4h, its deformation recovery rate could be reduced by 30%. Du et al. (2013) found that the tangential dimension stability of the P. tomentosa wood which has been treated under the condition of 195°C for 3h was 1.9 times of that of Fraxinus mandshurica.

5.1.2.2 Chemical Impregnation Reinforcing Modification

Lang et al. (2012) modified *P. euramericana* cv. ‘Neva’ with highly reactive amino methylurea using vacuum-pressure method. Succinic anhydride pre-treatment poplar was modified by in-situ polymerization using styrene monomer and Styrene-glycidyl methacrylate copolymer. Wang et al. (2013) grafted fast-growing poplar with methyl methacrylate monomer. Sun et al. (2015) treated poplar with PEG1000 and DMDHEU. Bi (2015) impregnated poplar using the compound of DMDHEU and methylolurea. Chen et al. (2013) prepared PF-CaCO₃-wood composite material. Some scholars impregnated poplar with water-soluble resin, which improved the density and mechanical properties of poplar wood. Moreover, it has been found that the plywood and laminated wood which was prepared by resin impregnated poplar veneer could reach the standard of outdoor timber or some structural timber.

The combined modification technology based on impregnation reinforcing has also been studied. Xu and Hou (2015) studied the heat treatment process of PF and UF impregnated wood and the properties of heat-treated impregnated wood, and found that heat-treatment could further improve the dimension stability of resin impregnated wood. The 150mm ×2400mm ×25mm PF impregnated wood was heat treated for 3h under 190°C and 160°C, respectively. These results show that the MOE and MOR of impregnated heat-treated wood were both about 50% higher than that of heat-treatment wood, and mechanical strength improved significantly (Unpublished data). Chai and Wang et al. (2015) treated poplar with MUF and boron modified agent, and the dimension stability and mechanical properties of the treated wood were comprehensively promoted. Additionally, Zhang et al. (2014) and Peng et al. (2015) explored drying process of 46mm and 25mm thickness UF impregnated *P. tomentosa* respectively, and found that the drying period of impregnated wood was longer than that of untreated wood.

5.1.2.3 Application of resin impregnated wood

Due to the better dimensional stability and higher hardness, density and mechanical strength, resin impregnated wood was used in furniture components and products. Li et al. (2015) used UF impregnated poplar to prepare the tenon assembly parts, and found that the tenon grip force was improved. In addition, Zhang et al. (2015) discussed the bleaching and finishing process of the furniture using resin impregnated modified wood.

5.1.3 The study on poplar wood-based panel

5.1.3.1 Applied basic research

Qin (2014) studied the relationship between surface free energy, wettability and bonding strength of PF poplar plywood. Wang (2013) studied the bonding interface property of poplar LVL. Chen et al. (2014) explored the differences of wood properties among different varieties of poplar plantation and their impacts on veneer bonding strength. Xu et al. (2015) analysed the effects of poplar dynamic mechanical properties on energy consumption during hot mill.

5.1.3.2 Raw material and adhesive

Raw materials diversification is an important direction of poplar wood-based panels. Some mixing raw materials like poplar-straw, poplar-waste paper, poplar-paper sludge, poplar-reed, and poplar-bamboo were used in producing particleboard plywood or MDF.

The development of environmental protection (low formaldehyde or formaldehyde-free), water resistant adhesive, and even non-adhesive bonding technology are important research directions in poplar wood-based panel industry. The use of high density polyethylene (HDPE) to replace the traditional synthetic resin wood adhesive has opened up a new direction. Soybean adhesive was modified aimed at its water resistance and mildew resistance. Guo et al. (2014) tested the poplar plywood non-adhesive bonding by wood liquefaction technology. Xie (2013) and Jin et al. (2014) discussed the non-adhesive bonding process and chemical characteristics of poplar fibreboard by using the bonding effect of lignin. Furthermore, Liu et al. (2012) introduced the oxygen plasma technology to modify the enzymatic hydrolysis lignin in order to improve the ‘self-bonding’ properties of poplar fiber.

5.1.3.3 Development of new products
In these years, structural poplar artificial board has become an important research field in the processing and utilization of poplar in China. Huang et al. (2013) produced the LVL using high-frequency hot-pressing technology. Liu (2012) discussed the miter quality improvement of poplar large span LVL. Heilongjiang Wood Science Research Institute determined the mechanical properties eigen value of poplar LVL. Glue application and hot-pressing technology, the mechanical model and the creep properties of Parallel Strand Lumber (PSL) were studied in Nanjing Forestry University. Zuo et al. (2014) chose poplar, SPF and pine as raw materials to develop prism glued-laminated timber. Similarly, Yangzhou University developed glued laminated columns using rotary veneer. Moreover, Nanjing Forestry University developed the laminated veneer hollow column.

With the development of nanotechnology in the world, poplar biomass nano-material has become a popular research area in China. Yang (2013) and Li et al. (2013) have prepared poplar micro/nano fibril from wood fiber, and explored the properties of polystyrene film which was modified by poplar micro/nano fibril. In other applications, Huang et al. (2012) and Pan et al. (2012) applied poplar micro/nano fibrils and MF/epoxy resin to prepare composite material. Liu et al. (2015) used poplar Nanocrystalline Cellulose (NCC) to improve the thermodynamic property of soybean adhesive.

There are also many other poplar products, such as lightweight foam material, wood-organic aerogel composite materials (Li, 2013), sliding bearing (Wu et al., 2012), copper plating at man-made board (Hu et al., 2013), aluminum-wood decorative composite, Dyed poplar veneer and products, etc.

5.1.4 Utilization of poplar wood pulp and biomass
Yu et al. (2013), Wang et al. (2014), Tang et al. (2014) studied poplar pulping process of alkaline hydrogen peroxide pre-treatment, nitric acid method and no-catalyzed glycerol method, respectively. Du et al. (2014) studied the effects of sodium bisulfite pre-treatment on the chemical composition and enzymatic hydrolysis of poplar pulp. Zhang et al. (2012) and Qi et al. (2013) studied the effects of low and high consistency refining on the property of poplar PRC APMP. Wang et al. (2013) used ultrasonic treatment to improve the properties of poplar APMP fiber.

Comprehensive utilization of waste water from pulp and paper making has been the focus of pulp and paper industry. Su et al. (2013) studied the thermogravimetric characteristics of aspen APMP effluent solid under different temperature and heating rate. Li et al. (2014) tried to use aspen APMP pulp treatment waste liquor in surface sizing of fluting medium. In order to develop and utilize the biomass in pulping waste liquor, Dong et al. (2014) analysed the compositions of APMP effluent. Before used to produce biofuel, lignocellulose was always pre-treated by dilute-sulfuric acid hydrolysis. Fang et al. (2015) measured the polysaccharide conversion rate to find the suitable particle size range in dilute-sulfuric acid hydrolysis pre-treatment of poplar effluent.

5.2 Processing and Utilization of Willows
Fast-growing Willows like S. discolor, S. psammophila, Salicaceae and S. gordejevii are widely introduced and industrial application test are carried out in these years. Yang et al. (2012) found that the fiber length of S. gordejevii which is 2-3 years old and grown in eight areas of Inner Mongolia was too short to use solely in the producing of fiber board, but some of them can be used as high quality pulp raw material. Application researches were focus on S. discolor, S. psammophila and Salicaceae in these years. Based on the traditional crafts and weaving tools industry, researchers have studied the utilization of willows in artificial boards, pulp, carbon materials, and bioenergy.

In the field of pulp and paper, Shandong Polytechnic University chose S. psammophila as raw material to study the optimal technological conditions of P-RCAPMP high yield pulping and the effects of xylanase, laccase-mediator and laccase-xylanase treatment on the pulp properties and lignin structure. Furthermore, Yuan (2012) studied the biobleaching technology and mechanism of S. psammophila chemical pulp.

Nanjing Forestry University found that the fiber morphology of S. discolor was similar to P. simoniix P. nigra, and its main chemical compositions were nearly the same as Fraxinus mandshurica and triploid Populus tomentosa. In addition, some scholars have studied the production process of Salix discolor products such as LVL, fibreboard, particleboard (Dong et al., 2013), and reconstituted wood. Inner Mongolia Agricultural University has found out that S. psammophila could be used as raw material for the production of MDF, light wall material and ultra-light material combined salix fiber with waste paper fiber. Moreover, Zhengzhou University studied the preparation process of microcrystalline cellulose from S. psammophila. In the field of bioenergy development, Inner Mongolia Agricultural University studied the baking characteristics and biomass baking process of S. psammophila (Liang, 2014).

5.3 Pulp production from poplar wood in China
There are 34 wood pulp manufacturers in China, with 51 wood pulp lines in total and an annual grand total wood pulp production capacity of 10.73 million metric tonnes. Among these 51 wood pulp lines, poplar wood chips alone or poplar-eucalypt wood chip mixtures are applied as raw fiber materials in 25 pulp lines, where P-RC APMP or CTMP pulping processes were installed for production of bleached chemimechanical pulps, mainly. Those pulp lines are located in areas such as Yangtze river basi, the plain between the Yellow River and Huai River, North China Plain and Northeast regions, including manufacturers such as Shandong Chenming paper group Co. Ltd., Shandong Sun paper Co. Ltd., Huaitai group Co. Ltd., Golden east (Jiangsu) Co. Ltd., Hunan Puyang Longfeng Paper
Industrial Co. Ltd. and Henan Jiaozuo Ruifeng Paper Industrial Co. Ltd. etc (Table 2). Since some specific high-quality wood properties for pulp wood, with suitable basic density and light wood colour, pulp lines using poplar wood chips achieve good performances including lower chemical consumption, lower specific refining energy and higher pulp yield and so on. Thus, high quality pulps could be produced from poplar wood chips in present pulping lines.

Meilun Paper Co. Ltd. of Chenming Group, located in Shandong province, has installed a BCTMP pulping line with an annual production capacity of 250,000 metric tonnes of bleached chemimechanical pulps, using poplar-eucalypt chip mixtures for bulky pulps as furnish to produce coated ivory cardboard and art paper products. All facilities were supplied by Valmet Co., Finland. Their tech-economic specification could be summarized as: Dosage of caustic soda 40-60 kg/mt, hydrogen peroxide 70-100 kg/mt, specific refining energy 1100-1300 kWh/mt, pulp freeness 250-350 mL CSF, bulk >2.40 g/cm³, tensile index >24 N.m/g, brightness 72-80%, opacity >88%.

Yueyang Paper Industrial Holdings Co. of Tiger forest-paper group had installed 2 chemimechanical pulp lines, the first APMP production line in the world with an annual production capacity of 30,000 metric tonnes of poplar pulp was installed in 1997, and a P-RC APMP production line with an annual production capacity of 100,000 metric tonnes of poplar pulp was installed in 2005, using American black poplar hybrids wood from plantations in Tongtianhu lake basin as fibrous material. All poplar pulps are applied for manufacturing News print and LWC grades. Multiple modifications and technical optimization had been taken for its P-RC APMP lines, resulting in reduction of production cost and improvement on pulp qualities, for instance, Dosage of caustic soda 40-50 kg/mt, hydrogen peroxide 60-80 kg/mt, specific refining energy 1200-1500 kWh/mt, pulp freeness 150-250 mL CSF, bulk 1.80-2.30 g/cm³, tensile index 32-40 N.m/g, tear index 3.0-4.0 mN.m/g, brightness 76-80%, opacity >85%.

Jiaozuo Ruifeng paper industrial co. Ltd. completed its P-RC APMP pulping lines with an annual capacity of 150,000 mt pulps in 2006, using commercial chips from P. tomentosa hybrids plantations growing on the plain between the Yellow River and Huai River, to produce bleached poplar pulps. The pulping system was supplied by Anritz AB Austria and efficient treatment system Park Co. Holland. Its technical economic parameters are specified as follows, dosage of caustic soda 50-60kg/mt, hydrogen peroxide 60-80kg/mt, specific refining energy 1000-1200 kWh/mt, freeness 250-350 ml CSF, bulk 2.40 g/cm³, tensile index 24 N.m/g, brightness 76-80%. Those pulps could be applied into production of the paper grades: off-set paper, LWC, news print, art paper, carbon free copying paper and LWC base paper etc.

Table 2 List of Bleached chemi-mechanical pulps using poplar wood chips in China

<table>
<thead>
<tr>
<th>Enterprises</th>
<th>Annual capacity, 10,000 mt/a</th>
<th>Start up time</th>
<th>Wood</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu Yang Longfeng</td>
<td>10</td>
<td>2005</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Jiaozuo Ruifeng</td>
<td>15</td>
<td>2006</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Henan Xinya</td>
<td>10</td>
<td>2007</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Yuanjiang Paper</td>
<td>20</td>
<td>2014</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Yueyang Forest-paer</td>
<td>10</td>
<td>2005</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Yueyang Forest-paper</td>
<td>3</td>
<td>1997</td>
<td>Poplar wood</td>
<td>APMP</td>
</tr>
<tr>
<td>Chenzhou Yurong</td>
<td>17</td>
<td>2013</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>BCTMP</td>
</tr>
<tr>
<td>Jilin Chenming</td>
<td>9</td>
<td>2013</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Golden east Jiangsu</td>
<td>26</td>
<td>2011</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Bohui, Jiangsu</td>
<td>51</td>
<td>2013</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Meili, Ningxia</td>
<td>10</td>
<td>2007</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Yinhe, Shandong</td>
<td>10</td>
<td>2011</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Sun paper, shandong</td>
<td>22</td>
<td>2013</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Sun paper, shandong</td>
<td>15</td>
<td>2011</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Sun paper, shandong</td>
<td>19</td>
<td>2009</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Sun paper, shandong</td>
<td>10</td>
<td>2007</td>
<td>Poplar wood</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Zhongmao sengyuan, Shandong</td>
<td>10</td>
<td>2006</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Meilun, Chenming</td>
<td>6</td>
<td>2003</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Meilun, Chenming</td>
<td>17</td>
<td>2011</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Meilun, Chenming</td>
<td>25</td>
<td>2004</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Zhengda, shandong</td>
<td>9</td>
<td>2010</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Huatai, shandong</td>
<td>11</td>
<td>2004</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Bohui, shandong</td>
<td>22</td>
<td>2009</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
<tr>
<td>Bohui, shandong</td>
<td>22</td>
<td>2004</td>
<td>Poplar and eucalypt chip mixtures</td>
<td>P-RC APMP</td>
</tr>
</tbody>
</table>

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6. Environmental Applications

6.1 Carbon sink function of poplar plantation

The carbon fixation ability of forests in China was primarily derived from forest plantations. Among the different types of plantations, poplar plantations have great potential in carbon sequestration in China due to their fast growth and high productivity. The carbon storage of poplar plantations accounted for 15.9% of total plantations in China.

6.1.1 The carbon sink of poplar plantations in China

The researches related to carbon sink of poplar plantations in China have made remarkable progress. For example, the Beijing Forestry University (BFU) investigated the carbon storage and density of poplar plantations according to the data of the Seventh National Forest Inventory. The total carbon storage and carbon density of poplars in China was 261.84 Tg and 25.92 t·hm⁻², respectively, and the carbon storage and density of poplar plantations was 179.22 Tg and 23.67 t·hm⁻², respectively. In Inner Mongolia, Henan and Shandong, the carbon storage was 35.45, 24.51 and 22.42 Tg, respectively, which accounted for 55.9% of the total carbon storage in China. Carbon storage in young- and middle-aged poplar plantations was 117.95 Tg, accounting for 65.9% of the total, i.e. showing great potential in carbon sequestration.

6.1.2 Carbon sink of poplar plantations in typical areas in China

The Nanjing Forestry University (NFU) estimated that the carbon storage and density of poplar plantations were 138.128 Tg and 150.389 Mg·hm⁻², respectively, in Jiangsu province. The NFU used the data of forest resources assessment in Jiangsu province to analyze the carbon storage distribution of poplar. They found that there were large differences in regional carbon storage. The poplar plantation exhibited a huge potential in carbon sequestration and the differences in carbon storage of poplar plantations of different ages were mainly caused by the carbon storage of tree layer.

BFU studied the carbon storage of poplar plantations in Heze, Shandong Province based on Landsat TM5 data. The carbon storage was 13.93 Tg accounting for 25.39% of forest vegetation in Shandong Province. The carbon density was 43.82 t·hm⁻₂, which was 21.82% higher than the national average level. The Chifeng Institute of Forestry Science found that the carbon density of tree, grass, litter and soil layer were 31.83, 0.13, 0.65 and 72.38 t·hm⁻², respectively. The Xinjiang University found that the carbon density of hungriness shrubbery was 0.47 t·hm⁻² after afforestation in Karamay of Xinjiang. The Institute of Geographic Sciences and Natural Resources Research of Chinese Academy of Sciences investigated the poplar plantations in Tianjin city. Total ecosystem carbon storage of young, medium and mature poplar plantations were estimated to be 84.3, 121.0 and 121.7 t·C·hm⁻², respectively. The carbon storage of poplars measured by the Anhui Academy of Forestry was 196.0 t·hm⁻² in Yixiu District of Anhui Province. Whereas, the value measured by Hubei Academy of Forestry ranged from 41.3 to 117.1 t·hm⁻² in 4- to 8-year-old plantations in Jianghan Plain. The Linyi University found that the microbial biomass carbon in middle and mature poplar plantations were 120.7-323.9 and 183.7-418.2 mg·kg⁻¹, respectively. Thus, the poplar plantations in China could have a huge carbon sequestration potential in the future.

6.1.3 Effects of cultural operations on carbon sinks in poplar plantations

At present, there are many researches on different cultural operations to promote the carbon sequestration of poplar plantation in China. The tree carbon of D1 (wide and narrow row + subsurface drip irrigation with water, fertilizer + intercropping cotton and wheat) and D2 (wide and narrow row + irrigation + alfalfa intercrop) were 53.7% and 7.9% higher than that of CK (uniform spacing + irrigation + intercropping cotton), respectively, in 4-year-old triploid P. tomentosa plantations in the Yellow River flood plain of Shandong province. The annual carbon sequestration capacities were 14 and 16 t·hm⁻², respectively, which were higher than that of CK (9 t·hm⁻²). The technique for increasing carbon sink in this area was the combination of wide and narrow row planting scheme, subsurface fertigation, and alfalfa intercropping.

The carbon storage under subsurface drip irrigation was 76.5 t·hm⁻², which was 54.2% higher than that under normal irrigation in 6-year-old poplar plantations of I-214 at sandy soil in Chaobai River in Beijing. The carbon storage of tree story, understory plants, litter floor and soil of stump grafting plantation were 2.6, 4.1, 3.1 and 1.1 times of that in reforestation plantation in the 9-year-old protection poplar plantation in Daxing of Beijing, and the annual net carbon increment was 10.0 t·hm⁻². Therefore, stump grafting is an carbon sink enhancement technology, which could serve as an improvement of poplar plantation protection method in Daxing District, Beijing. Carbon storage of three different patterns of poplar-crop intercropping patterns were studied with a biomass measurement method in the North of Jiangsu Province by NFU. Results showed that soil carbon storage of the three patterns were 71.19, 40.67 and 42.64 t·hm⁻², respectively.

6.2 Environmental protection and control
6.2.1 Sandy land control
Although the role of poplar in sandy land control is controversial in China, some breakthroughs have been made in the recent years. Sand-fixing poplar forests with low coverage banded planting scheme has been planted by the Chinese Academy of Forestry (CAF) in southern Horqin, and its effects on sand fixing was significant, especially under the forest band with 20 m width. The ‘low coverage sand fixing method’ achieved that quicksand could be fixed completely when the vegetation coverage reached 20%, which was a breakthrough of the traditional concept that the quicksand could not be fixed with a vegetation coverage under 40%. It could not only accelerate the natural restoration process of the inter-band vegetation, but also it can also improve soil conditions.
In the east Bashang forest-steppe and northwest basin-mountain of Hebei province (two types of heavy sandification lands), a model of comprehensive assessment for sand-fixing plantations was built up by CAF based on experiments conducted in the fifteen types of sand-fixing stands composed of different tree species including Larix principis-rupprechti Mayr, Pinus sylvestris, P. beijingensis, Ulmus pumila L., Platyclusus orientalis, P. simonii Carr., P. popular’s and P. bolleana. Research results showed that concerning the scattered sandy land of northwest basin-mountain in Hebei province, P. popular’s and P. bolleana could be used for afforestation. In order to understand the effect of sand-fixing plantation in scattered sandy land, stand structure factors and sand transporting rate were observed by Hebei Academy of Forest Science (HAFS) focusing on eight types of poplar stands including three tree species of P. simonii Carr., P. popular’s and Populus bolleana. The research results showed that the sand transporting rate was influenced by canopy density and average tree height in horizontal and vertical direction, respectively, and their coupling effects could significantly decreased the sand transporting rate. In general, different types of sand-fixing poplar plantations could intercept sand and reduce sand erosion to different degrees.

6.2.2 Farmland shelterbelt
To protect farmland from natural disasters and improve productivity, a large area of shelterbelts consisting of poplars have been widely planted in the northern part of China. The research conducted by the Second Institute of Forestry Monitoring and Planning of Inner Mongolia Autonomous Region showed that, soil physical properties in the shelterbelt could be improved, such as reduction of the coarse and middle sand content, increase of clay particle content and soil porosity, and increase of soil organic matter and total nitrogen, etc. Besides, under the protection of the shelterbelt, the production of maize, wheat and soybean increased by 6.5%, 6.4% and 20%, respectively. The Xinjiang Academy of Forestry Sciences found that, in Hetian region of Xinjiang province, the proportion of biomass in P. bolleana shelterbelt accounted by trunk increased with forest age. The soil carbon storage decreased with depth in stands within different age classes, and the carbon density was higher in surface soil than in other layers. Besides, carbon storage in mature stands was 17.4 times of that in young stands.

6.2.3 River and beach land treatment
The long-term subsidence and severe soil erosion on the ground contributed to the formation of sand shoals and flaky beaches with different width along the downstream segment of the Yangzte River and Yellow River and its tributaries. Beaches of Yangzte River are low and flat with an altitude ranging from 13 to 17m. The loose and fertile stratification soil is exposed out of water during common water period but often gets flooded during the flood period. Thus, afforestation in beaches should apply the appropriate tree species to the suitable planting site, and subsequently improve the afforestation quality in beaches in the middle and lower reaches of the Yellow River and Yangzte River, and establish good ecological network system in these beaches. In order to select the poplar clones suitable to be planted on the beaches of Yangzte River, the growth and survival rate of twenty poplar clones were tested and compared by NFU. The results showed that the integrated values of poplar clone 895, clone 324 and clone 1388 were the highest. The research conducted by Anhui Agricultural University indicated that, afforestation of poplars in beaches could significantly enriched the botanical community diversity, and limited the development of snail community. In addition, under the background that afforestation has been conducted in a large area of the Yangzte River beach, NFU investigated the effects of thinning treatments on the nitrogen transformation in poplar plantations, which provided the theory basis for plantation structure adjustment and big-diameter timber poplar cultivation. There is a larger area of beach in the middle and lower reaches of the Yellow River, and poplar is the main species for afforestation in this region. Thus, afforestation with poplar species in beaches could not only increase the ecological benefits, but also increase the economic benefits. For example, the water bureau of Binzhou City investigated the effects of different vegetation types on sand fixation, water saving and soil protection, and soil quality improvement. The research results showed that, poplar plantations had strong ability in resisting wind erosion, and could improve water storage in surface soil and soil permeability to a certain extent.

6.2.4 Phytoremediation of polluted soil and water
Poplars are often used for phytoremediation due to their fast growth, deep rooting and strong water absorption ability. Poplars can uptake a lot of pollutants, including fertilizer, metal, non-metal, etc. However, if the polluted water is used to irrigate the forests, the chemical composition in it will do harm to the trees. Damage caused by polluted water include leaf damage, leaf early maturity and aging, biomass decrease, etc. A better understanding of the negative influence posed by polluted water on trees in short term is important, since it helps to predict the influences in long term. To study the effects of domestic waste water on soil microbial community, biomass and enzymes activities, a wastewater irrigation experiment
was conducted by Zhengzhou Agriculture and Forestry Science Institute in poplar woodland with different irrigation volumes (0, 300, 600,900, 1200 and 1500 m$^3$·hm$^{-2}$). Results showed that when the irrigation volume was 600 -900 m$^3$·hm$^{-2}$, the amount of soil microorganism, the content of soil microbial biomass and the enzyme activity was higher. And the soil indicators changed with irrigation volume. The soil microbe amount decreased, the soil physical and chemical properties also showed a decreasing tendency. The Chinese Academy of Forestry did a research about the influence of compost sludge on the two varieties P. euramaricana ‘Lingfeng3’ and P. euramerica ‘Guariento’ based on greenhouse pot test, the results showed that some of the heavy metal elements such as Cu, Zn, As, Hg mainly accumulated in roots, and Cd mainly accumulated in leaves; with the addition of sludge, the accumulation of heavy metal in leaves, stems and roots increased, especially in roots. BFU did a research on the effect of irrigation with different dilutions of paper mill effluents (PME) on growth and nutrient status of P. tomentosa seedlings. The findings showed that PME irrigation had no significant effect on the pH and available P content of soil, while percentages of organic matter, total N, and available N increased significantly with increasing concentration of PME. Thus, PME irrigation promoted the growth of P. tomentosa seedlings, and increased plant nutrient status and soil fertility. The dilution concentration of PME for P. tomentosa should be 16%—25%. A soil culture experiment was carried out by the Guangxi University to investigate the effects of Cd, Zn and Pb combined pollution on biomass, heavy metal concentration and total uptake, bioaccumulation coefficient (BCF), transportation factor (TF) in 14 poplar and willow species. Results showed that with the increasing of heavy metal concentration in soil, heavy metal concentration and total uptake in poplar and willow species increased significantly, BCF decreased obviously, whereas TF showed no change. The absorption and enrichment of heavy metal elements by leaves of P. euramerica cv. ‘Neva’ was analyzed by CAF through content assessing of heavy metal elements in soils of three forest lands at Fangshan District in the southern suburb of Beijing. P. euramerica cv. ‘Neva’ could absorb and accumulate Pb, Cd, Cu and Zn in soil but showed different capacities of absorption and accumulation. Moreover, its Cd absorption and accumulation capacity was strong, whereas its Pb and Cu enrichment capacities were relatively poor. The analysis of the composition of the polychlorinated biphenyls in various organs of P. tomentosa and reed plant was conducted by the Agricultural University of Hebei, it was speculated that poplar and reed had a certain bioremediation effect on polychlorinated biphenyls.

III GENERAL INFORMATION

1. Administration and Operation of the National Poplar Commission or equivalent Organization 李金花

(a) Indicate here any changes in the composition of the Commission, amendments to its statutes, changes of address, etc.

The National Poplar Commission of China was established in 1980 and renamed as the Poplar Special Commission (PSC), a secondary sub-society of Chinese Society of Forestry (CSF) in 1998. The PSC secretariat is affiliated to and located in Research Institute of Forestry, Chinese Academy of Forestry, Beijing. In 2009, the seventh term of the board of the Poplar Special Commission has been reelected, presently comprising the following members:

- Director, Academician and Prof. Yin Weilun,
- Vice Director, Prof. Lu Mengzhu,
- Vice Director, Prof. Fang Shenzhu,
- Vice Director, Prof. Lv Jianxiong,
- Secretary Genera, Prof. Lu Mengzhu

The contact address of the Commission is as follows:

Poplar Special Commission, Chinese Society of Forestry Research Institute of Forestry, Chinese Academy of Forestry Yibeyuanhou, Beijing 100091 Tel: +86 10 62889606 Fax: +86 10 62872015 Email: lutmz@caaf.ac.cn

(b) Report briefly on meetings, congresses and study tours, and on other activities of a general nature organized by the Commission at the national level.

With the leadership of Chinese Society of Forestry (CSF), the Poplar Special Commission (PSC) is annually active in organizing and hosting conferences or meeting of CSF on scientific and technological themes each year as well as several meetings of the board during the last four years. In some cases, PSC also is also involved in public discussions, technical consulting activities and provides technical advices to relevant organizations dealing with poplar and willow.

(c) Indicate also the difficulties encountered by the Commission in the course of its work and any lessons learned

2. Literature
List here publications on poplars and willows issued in the period under review, (2012-2015) including technical papers presented at meetings, congresses, etc.

Genetics and Breeding


Poplar PdMYB221 is involved in the direct and indirect regulation of secondary wall biosynthesis during wood formation. Scientific reports, 5.


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**Breeding by ploidy**


Li XD, Fan JF, Qiu X, Lyu XF. 2015. Identification and selection on the cold tolerance in the hybrids of Populus deltoids × Section Tacamahaca (Chinese). Journal of Northwest Forestry University, 30(2):100-104.


Environmental use


Zhao D, Ma X. 2012. Study on carbon storage and carbon density of poplar forest in Jiangsu Province (Chinese). Jilin Agriculture, 05: 139-140.


Qi HT, Bai LP, Lu HB, et al. 2014. Effect of Composted Sewage Sludge on the Changes of Heavy Metal Accumulations
Zhang CY. 2013. The Effects of Carbon Dioxide and Burkholderia onRemediation of Heavy Metal by Poplar and Willow (Chinese). Guangxi University, 1-50.
Disease Diagnosis and Identification
Disease Resistance


Pest Control


Chi YJ, Yi HW, Li DD. 2012. Antagonistic action of conidial extracts of *Trichoderma harzianum* on *Cytospora chrysosperma* and *Magnaporthe grisea*. Journal of Northeast Forestry University, 40(9): 90-92,106.


Utilization


He SS. 2015. Investigating the properties of small diameter Salix discolor and its medium density fiberboard. Thesis for Masters Degree of Nanjing Forestry University.


Li Q. 2012. Study on basic theory and key technology of salix medium density fiberboard reinforced by poplar or willow wood fiber. Thesis for Doctors Degree of Inner Mongolia Agricultural University.


Yang Y. 2014. The research on salix discolor LVL. Thesis for Masters Degree of Nanjing Forestry University.


Cultivation


Wang YK, Chang X. Scott, Fang SZ, Tian Y. 2014b. Contrasting decomposition rates and nutrient release patterns in mixed vs


3. Relations with other countries
Exchange of scientific materials and research-relevant ideas in order to promote science has been frequently done thanks to the generosity from both the Chinese and foreign sides. Permanent connections has been held with specialists from Italy, USA, Canada, Germany, France and UK.

4. Innovations not included in other section
List here any new developments not included elsewhere.