Development of Willow Research
In Jiangsu Academy of Forestry

Associate professor
SHI, Shizheng

Nov. 3, 2008
Brief introduction of JAF

• History

• 1941-1945: Central Laboratory of Forestry at Geleshan Town in Chongqing

• 1945-1949: Central Laboratory of Forestry in Nanjing.

• 1958-1959: Jiangsu Experimental Station of Forestry

• 1959-1999: Jiangsu Institute of Forestry

• 1999- now: Jiangsu Academy of Forestry
• **Staff**

  - There holds 58 active researchers including 24 core members.

  **Our academic journal**

  **Our homepage:** [Http://www.jaf.ac.cn](http://www.jaf.ac.cn)
• **Our research**

  – **Genetics and Breeding of Forestry**

    • It mainly aim at the breeding of indigenous tree species in Jiangsu Province and 12 influential tree species.

  *Populus deltoides ‘35/66’*  
  *Paulownia × jiangsuensis*  
  *Louisiana cypress*  

  *Rose*
• **Research on forest ecology**
  
  – Research on establishing shelterbelt system
  
  – Research on integrated technology of agro-forestry management
  
  – Research on integrated technology for management in the mountainous area
• **Research on technology for protection and management of forest resource**
  
  – Research on technique for comprehensive control of pine wood nematode
  
  – Research on diseases and pest control of poplar and other economic trees, including pine, cypress, bamboo, chestnut, etc.

Biological control for *Scleroderma guani*

Fumigation of infected wood

Medical control
Brief introduction of JAF

- **Main achievement**
  - 40 more excellent tree species
  - 24 more cultivation technology of relational tree species
  - 40 more papers every year
  - 40 more national, provincial and ministerial awards in the last 20 years
  - Three patents of invention and utility-type
  - 10 more monographs
Summary of research on willow

1. Introduction

2. Germplasm resource and its distribution

3. General situation of willow research
   – Collection and conversation of germplasm resource
   – Selection and breeding
   – Cultivation
   – Phytoremediation

4. Project and development

5. Achievements
1. Introduction

- Growing history and cultural connotation of willow in China

  - Growing history of long standing:
    - 50,000a ago — pollen
    - 4,500a ago — morphologic
    - 3,000a ago — firewood

  - Implication of urging to stay and longing, missing

    Willow, as whose pronunciation in Chinese character is “liu”, a homonym of another word meaning stay and lingering, used to appear in the poems, prose, and verse in the past dynasties, meaning understanding of, sympathy for and hospitality to intimate friends. And as typically having fine slender branches and narrow, tapering leaves, taking a form of long silk, which is “si” in Chinese pronunciation, meaning missing and longing, willow also implies the thinking of or longing for the relatives and friends afar.
Introduction

- **Metaphor of being driven to an unstable society**
  Willow, as whose seed scattered from small capsules has cotton-like threads, aiding in spring wind dispersal, germinating within one or two days after landing on moist soil, reaches flowering age within a few years, but short-lived, connoting the social beauties driven to an unstable society (even to prostitution).

- **Quality of modesty, self-effacement**
  As the weeping willow, which is commonly seen everywhere, has the branches drooping to ground and approaching to the root, willow symbolizes modest gentleman and the people with a conscience or without forgetting their past sufferings.
• **History of research on willow in JAF**

  – In 1962, Mr. Zhongyu Tu initiated the research on willow
  – In 1972, the team of research on willow was established
  – In 1980, regional tests were carried out in 15 provinces
  – In 1990, we selected four improved varieties, including *Salix × jiangsuensis* CL ‘J172’ and CL ‘J194’, and got the Second Prize of the State Invention.
  – In 2004, nursery of willow germplasm resource was erected in China.
  – In 2007, Gene Pool of Jiangsu Willow Provenances was established.
  – Until now, we have undertaken 9 National Key R&D Programs, 16 Key Sci-tech Programs of Jiangsu Province.
Introduction

- **Research team**

  TU, Zhongyu
  Founder of the research on willow in China

  PAN, Mingjian
  Breeding of willow and poplar.

  GUO, Qun
  Cultivation of willow.
WANG, Baosong  Professor, Breeding and cultivation of willow and poplar.

SHI, Shizheng  Associate Professor, Breeding of willow

Introduction
WANG, Youliang  Associate professor
  Research on phytoremediation of willow

HAN, Jiefeng  Associate professor
  Research on cultivation of willow

ZHANG, Jue  Research assistant
  Research on insect and pest control of willow

JIAO, Zhongyi  Research assistant
  Research on breeding of indigenous tree species

SHUI, Dezhong  Research assistant
  Research on salty resistance of willow

WANG, Hongling
  Research on MAS
International Exchanges and Cooperation

Now, we keep exchanges and cooperation with relational experts from over 10 countries.

Professor Yao, Jialong
Chief scientist of Pure Power Global in New Zealand
Exchanges with experts

from America, Japan, Korea, Portugal, Spain, etc.
There are 526 species or varieties in the world and most of them distribute in N20° - N70° regions of the Northern Hemisphere.
There are more than 257 species of willow in China, including over ten high utility value species, and about 50 species with breeding value.
Distributing at 1000~3000 m high altitude of mountainous area in North China, Northeast China, Central China and Southeast China, eg. *Salix wallichiana*.

Five distribution types of wild willow in China

**Willow scrub in alpine area**

Distributing at 3200 m high altitude, and various type varieties, eg. *Salix sclerophylloides* var. *sclerophylla*, which are 0.3~1.5 m high.

**Willow scrub in montane area**

Distributing at 1000~3000 m high altitude of mountainous area in North China, Northeast China, Central China and Southeast China, eg. *S. wallichiana*.
Distributing at swampland, lakeshore and river shoal, eg. *S. rosmarinifolia* in swampland of Northeast China, *S. viminalis* in Yangtze River beach, *S. triandrodies* and *S. suchowensis*, etc.

Distributing at drifting or semi-drifting sand dunes as pioneer plants, eg. *S. michelsonii*, *S. psammophila*, *S. caspica*, etc. And they have resistance to sand burial and drought.
Willow forest in beach and river side:

Distributed at the flat area, including *S. matsudana*, *S. babylonica*, *S. chaeonome-loides*, *S. alba*, etc. They are the most common willows in our daily life.
## Main willow species with pragmatic value in China

<table>
<thead>
<tr>
<th>Section</th>
<th>Tree Size</th>
<th>Shrub</th>
<th>Shrub or Bush</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetraspermae</td>
<td><em>S. tetrasperma</em></td>
<td><em>S. mesnyi, S. donnii</em></td>
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<td>Urbanianae</td>
<td><em>S. maximowczii</em></td>
<td><em>S. chaenomeloides</em></td>
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<td>Wilsonianae</td>
<td><em>S. cavalieri, S. wilsonii</em></td>
<td><em>S. rothgyami</em></td>
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<tr>
<td>Pentandrae</td>
<td></td>
<td><em>S. paraplesia</em></td>
<td><em>S. pentandra</em></td>
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<tr>
<td>Amygdalae</td>
<td></td>
<td><em>S. songarica</em></td>
<td><em>S. triandra</em></td>
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<tr>
<td>Salix</td>
<td><em>S. matsudana, S. babylonica, S. alba, S. koriensis, S. eriocarpa, S. fragilis, S. heteromera, S. capitata, S. sphaeronyphoides</em></td>
<td><em>S. chienii</em></td>
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<td></td>
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<td><em>S. pierotii</em></td>
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<td><em>S. longistamina</em></td>
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<td><em>S. sphaeronympe</em></td>
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<tr>
<td>Magnificae</td>
<td><em>S. magnifica</em></td>
<td><em>S. moupinski</em></td>
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<tr>
<td>Vexi</td>
<td></td>
<td><em>S. caprea, S. straakensis</em></td>
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<tr>
<td>Daphnella</td>
<td><em>S. rorida</em></td>
<td><em>S. raddeana, S. wallichiana</em></td>
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<tr>
<td>Vimen</td>
<td><em>S. sacalinensis</em></td>
<td><em>S. rehderiana</em></td>
<td><em>S. viminalis, S. turanica, S. siwzewii, S. characta</em></td>
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<tr>
<td>Subviminalis aesiae</td>
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<td><em>S. dasyclados</em></td>
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<tr>
<td>Cheilophilae</td>
<td></td>
<td><em>S. gracilistylo</em></td>
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<tr>
<td></td>
<td></td>
<td><em>S. integra, S. kochiana</em></td>
<td></td>
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<tr>
<td>Helix</td>
<td></td>
<td><em>S. microstachya, S. cheilophila</em></td>
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<tr>
<td></td>
<td></td>
<td><em>S. linearistipularis, S. sungfianica, S. suchowensis</em></td>
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<tr>
<td></td>
<td></td>
<td><em>S. caspica, S. teufulis, S. michelsonii, S. gracilior, S. carmarica, S. psammophila, S. capusi</em></td>
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<tr>
<td>Flavidae</td>
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<td><em>S. gordejevi</em></td>
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<tr>
<td>Total</td>
<td>15</td>
<td>14</td>
<td>27</td>
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</table>
Typical willow resources in China

- Widest distribution and highest increment: *S. matsudana*. They are distributed in all of the 28 provinces.
- Dwarf willow: The tree height is 10 cm.
- Wicker willow for handicrafts: *S. intergra* and *S. sinopurourea*. They have few branches which are flexible, and easy to obtain wide or thin wickers.

Wickers of *S. intergra*  
*S. sinopurourea*
Willow with stress resistance:

- *S. alba* in Xinjiang can grow normally in 0.706% saline content.
- Good varieties of *S. matsudana* × *S. alba* can keep growth at a speed of 3cm each year when submerged in the flood after plantation.
- *S. psammophila* has well drought resistance.

Ornamental willow: Weeping willow and *S. argyracea*. The former variety is the most common garden trees, and the later most commonly used in making cut and dry flower.
Germlasm Resource and Distribution

One of the willow varieties with most resistant to salinity - *S. alba* in Xinjiang

Ornamental Willow

*S. argyracea* and weeping willow
3 General situation of willow research

- Collection and conservation of willow germplasm resources
  - Since 1962, we’ve collected 86 species and varieties and about 2000 optimum hybrid clones of willow on timber (such as wood, knitting), gardening, high biomass, ecological application.

For timber (S. matsudana)  High biomass (S. viminalis)  For ecological application  For gardening
Collection and conservation of willow

- The original and natural willow species which we’ve conserved, including over 50 varieties—arbor willow and 32 shrub willow varieties.
- The strains are listed on the basis of utility direction in the following table.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Breeding for timber (wicker): 26 species and 524 regional plants</td>
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</tr>
<tr>
<td>S. babylonica</td>
<td>56</td>
<td>S. koreensis</td>
<td>3</td>
<td>S. mats. var. anshanensis</td>
<td>1</td>
<td>S. caroliniana</td>
<td>3</td>
<td>S. wilsonii</td>
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<td>S. alba</td>
<td>78</td>
<td>S. fragilis</td>
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<td>S. paraplesia var. subintergra</td>
<td>16</td>
<td>Ch. arbutifolia</td>
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<td>S. magnifica</td>
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<td>S. capitata</td>
<td>2</td>
<td>S. nigra</td>
<td>26</td>
<td>S. babylonica × S. alba</td>
<td>2</td>
<td>S. bulkingensis</td>
<td>2</td>
<td>S. songarica</td>
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<td>S. variety</td>
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<td>S. mats. var. pseudo-matsudana</td>
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<td>S. magnifica</td>
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<td>S. matsudana</td>
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<td>Breeding for high biomass: 13 species and 166 parents</td>
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<tr>
<td>S. viminalis</td>
<td>3</td>
<td>S. wilsonii</td>
<td>8</td>
<td>S. chaenomeloides</td>
<td>6</td>
<td>S. linearistipularis</td>
<td>4</td>
<td>S. erocephala</td>
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<td>S. integra</td>
<td>80</td>
<td>S. caspica</td>
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<td>S. suchowensis</td>
<td>15</td>
<td>S. Saposhnikovii</td>
<td>2</td>
<td>S. cinerea</td>
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<tr>
<td>S. viminalis</td>
<td>32</td>
<td>S. alberti</td>
<td>1</td>
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<td>Breeding for garden: 9 species and 209 parents</td>
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<tr>
<td>S. × lecopithecia</td>
<td>4</td>
<td>S. alba</td>
<td>24</td>
<td>S. pseudo-lasinigne</td>
<td>1</td>
<td>S. turanica</td>
<td>5</td>
<td>S. caprea</td>
<td>13</td>
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<tr>
<td>S. babylonica</td>
<td>55</td>
<td>S. chienii</td>
<td>1</td>
<td>S. mats. f. tortuosa</td>
<td>2</td>
<td>S. yapiniana</td>
<td>2</td>
<td>S. radeana</td>
<td>1</td>
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<tr>
<td>S. sinopurpurea</td>
<td>36</td>
<td>S. aurita</td>
<td>2</td>
<td>S. chaenomeloides</td>
<td>6</td>
<td>S. gracilistyla</td>
<td>5</td>
<td>S. dasyclados</td>
<td>7</td>
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<td>S. neowilsonii</td>
<td>2</td>
<td>unknown</td>
<td>25</td>
<td></td>
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<td></td>
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<tr>
<td>For ecology or others: 34 species and 130 parents</td>
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<td></td>
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<tr>
<td>S. spaeronymphe</td>
<td>1</td>
<td>S. rorita</td>
<td>25</td>
<td>S. mats. f. pendula × S. alba</td>
<td>1</td>
<td>S. sunghianica</td>
<td>1</td>
<td>S. wallichiana</td>
<td>1</td>
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<tr>
<td>S. longistamina</td>
<td>15</td>
<td>S. alberti</td>
<td>1</td>
<td>S. nigra × S. babylonica</td>
<td>1</td>
<td>S. psammophila</td>
<td>1</td>
<td>S. pseudotamngii</td>
<td>2</td>
</tr>
<tr>
<td>S. paraplesia</td>
<td>8</td>
<td>S. siuzevi</td>
<td>3</td>
<td>S. babylonica × P. euphratica</td>
<td>1</td>
<td>S. luniensis</td>
<td>2</td>
<td>S. tenuijulis</td>
<td>3</td>
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<tr>
<td>S. maliensis</td>
<td>6</td>
<td>S. capus</td>
<td>4</td>
<td>S. psammophila</td>
<td>5</td>
<td>S. chalophila</td>
<td>19</td>
<td>S. Triandra</td>
<td>9</td>
</tr>
</tbody>
</table>
Collection and conservation of willow

- Totally 998 willow strains are selected as original clones for hybridization on the basis of the following three standards:
  - May replace the original strains whose parents cannot be conserved in Jiangsu.
  - Be improved original strains.
  - Be from improved candidate population.
Collection and conservation of willow

- About 22 ha nursery of original strains have been established for testing and breeding.

Central conservation plot in Nanjing

- Original arbor willow
- Original shrub willow
- Open nursery for species
Collection and conservation of willow

About 6.6ha conservation plot of original strains in Shuyang County

About 6.6ha experiment plot in Hongze County

About 6.6ha breeding nursery in Jiangdu County
Collection and conservation of willow

- Other important resources conserved in JAF
Collection and conservation of willow

Salix alba

Salix nigra
Collection and conservation of willow

*Salix fragilis*

*Salix rorida*
Collection and conservation of willow

*Salix wilsonii*  
*Salix neowilsonii*  
*S. caroliniana*
Collection and conservation of willow

*Salix suchowensis*

*Salix integra*

*Salix viminalis*

*Salix × leocopithecia*
Collection and conservation of willow

Salix aurita

Salix caprea

Salix songarica

Salix triandra
Collection and conservation of willow

Salix purpurea

Salix driophila

Salix yapiniana
• **Selection and breeding**

  – **Breeding Strategy**
Selection and breeding

- **Procedure of selecting clones**

  - Phenotypic selection of seedlings (2-yr old)
  - Test of clones (≥ 3 points)
    - Seedling selection in the 2nd year
  - Stand test of clones,
    - 1st early selection of stand in the 3rd yr
  - 2nd stand selection in the 5th year
  - Regional test of clones (≥ 3 points)
    - Rotation at the 10th year for stand selection
  - Rotation at the 10th year for stand selection
  - Clone identification, registration and popularization

Plantation of *S. × jiangsuensis* in the beach of Yellow River
Selection and breeding

- **Selection and breeding**
  - Distant hybridization: hybridization and backcrossing of *Chosenia* and *Salix* L.

  For the purpose of improving the stem style and cold resistance of new willow cultivars, Zhongyu Tu, research fellow of JAF, made *Ch. arbutifolia* cross with *S. babylonica* and *S. matsudana* in 1974, 1978, 1982 and 1984 respectively.

**Crossability of *Ch. arbutifolia* with *S. babylonica* and *S. matsudana***

<table>
<thead>
<tr>
<th>Combination</th>
<th>Num. of pollinated inflorescences</th>
<th>Num. of harvesting inflorescences</th>
<th>Num. of harvesting seeds</th>
<th>Num. of seeds per inflorescence</th>
<th>Num. of germinated seeds</th>
<th>Num. of seedlings</th>
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</thead>
<tbody>
<tr>
<td>mats. × mats.</td>
<td>174</td>
<td>174</td>
<td>12657</td>
<td>72.74</td>
<td>105</td>
<td>461</td>
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<tr>
<td>mats. × arb.</td>
<td>517</td>
<td>262</td>
<td>1155</td>
<td>2.23</td>
<td>105</td>
<td>34</td>
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<tr>
<td>bab. × bab.</td>
<td>50</td>
<td>9</td>
<td>59</td>
<td>1.18</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>(bab. × mats.) × arb.</td>
<td>38</td>
<td>16</td>
<td>314</td>
<td>8.25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>arb. × mats.</td>
<td>661</td>
<td>64</td>
<td>217</td>
<td>0.33</td>
<td>105</td>
<td>30</td>
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<tr>
<td>arb. × arb.</td>
<td>302</td>
<td>43</td>
<td>1373</td>
<td>4.53</td>
<td>334</td>
<td>699</td>
</tr>
<tr>
<td>(mats. × arb.) × mats.</td>
<td>101</td>
<td>101</td>
<td>11129</td>
<td>84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Selection and breeding

Although the weak growth vigor of F1, and choosing the strong plants from F1 as the female parent backcrossed with *S. matsudana*, made no obvious difference of the cross ability with the interspecific hybridization, the heterosis is obvious. By this way, we obtained improved clones, *S. × jiangsuensis* CL‘J194’.
• **Genetic variation of timber** basic density:
  – According to our research on 151 clones of 39 hybridizations, genetic variations of different hybrids or clones are significant ($\alpha=0.01$). There is no significant correlation of density with the tree height and DHB.

• **Papermaking properties** of willow:
  – We have studied the fiber characteristics of timber and pulping characteristic and their genetic variation of each $S. \times jiangsuensis$ variety, and the inter-varietal and age-class difference of these characteristics.
Selection and breeding

Fiber and its content of \( S. \times jiangsuensis \) varieties

Average length of fiber (mm)

Fiber content (%)

Average value of two counties: Jiangning and Fuyang

Jiangning County
Comparison of the relational economic characters of willow pulpwood with that of poplar aged 5
Research on selection and breeding for excellent varieties is mainly on breeding of timber plantation variety, variety with high biomass and ornamental variety, wicker variety and breeding for resistance.

Genetic improvement of plywood timber and pulpwood:

- Most of them are the hybrids of *S. babylonie*, *S. matsudana*, *S. alba*, *Ch. Arbutifolia*, etc. We have selected two improved varieties *S. × jiangsuensis CL ‘J172’ and CL ‘J799’*. The screened pulp yield rate of ‘J799’ by kraft process is up to 52% ~53%.
Selection and breeding

Summary of partial improved cultivars for pulpwood

\[ \text{Salix } \times \text{ jiangsuensis CL ‘J172’} \]
Average volume increment of wood per year can reach 18.18 m³/hm².

\[ \text{Salix } \times \text{ jiangsuensis CL ‘J333’} \]
The leaves are narrow lanceolar. Length and width of the leaves are 11.63 cm and 1.25 cm, and the rate of length/width is 9.3.
Selection and breeding

*Salix × jiangsuensis CL ‘J799’*
Annual average wood yields of five and nine-year-old pulpwood plantation are 15.89 m³/ha and 28.69 m³/ha. The fiber content is about 48.6%. And the average length and the rate of length / diameter of its fiber are 1.0847 mm and 47.22.

*Salix × jiangsuensis CL ‘J903’*
Annual average wood yields of five and nine-year-old pulpwood plantation are 20.22 m³/ha and 22.81 m³/ha. The fiber content is about 51.55%. And the average length and the rate of length / diameter of its fiber are 0.957 mm and 45.83.
– Genetic improvement of pitwood

• The mainly objectives are to increase the mechanical strength and reduce the crooked degree of the stem for the purpose of commercial pitwood production.

Interrelated index of the pitwood aged 9 in the beach of Yangtze River

<table>
<thead>
<tr>
<th>Clone</th>
<th>Volume per tree (m³)</th>
<th>Form factor</th>
<th>Form quotient (q₀.5)</th>
<th>Curvature of trunk (%)</th>
<th>Impact toughness (kg·f·m/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J795</td>
<td>0.1557</td>
<td>0.3973</td>
<td>0.5580</td>
<td>0.3483</td>
<td>1.292</td>
</tr>
<tr>
<td>J799</td>
<td>0.1551</td>
<td>0.3707</td>
<td>0.5103</td>
<td>0.3227</td>
<td>3.362</td>
</tr>
<tr>
<td>J903</td>
<td>0.1223</td>
<td>0.3287</td>
<td>0.4553</td>
<td>0.2403</td>
<td>4.391</td>
</tr>
<tr>
<td>J172</td>
<td>0.1006</td>
<td>0.3803</td>
<td>0.5120</td>
<td>0.3307</td>
<td>2.949</td>
</tr>
<tr>
<td>J308</td>
<td>0.0776</td>
<td>0.3280</td>
<td>0.4793</td>
<td>0.2360</td>
<td>2.984</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clone</th>
<th>Individual volume (m³)</th>
<th>Bending strength (kg·f/cm²)</th>
<th>Compression strength parallel to grain (kg·f/cm²)</th>
<th>Basic density (g/cm³)</th>
<th>Qualified percentage of pitwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J795</td>
<td>0.1557</td>
<td>855</td>
<td>382</td>
<td>0.4793</td>
<td>92.3</td>
</tr>
<tr>
<td>J799</td>
<td>0.1551</td>
<td>906</td>
<td>404</td>
<td>0.4364</td>
<td>42.6</td>
</tr>
<tr>
<td>J903</td>
<td>0.1223</td>
<td>991</td>
<td>408</td>
<td>0.4843</td>
<td>41.4</td>
</tr>
<tr>
<td>J172</td>
<td>0.1006</td>
<td>718</td>
<td>312</td>
<td>0.4170</td>
<td>56.3</td>
</tr>
<tr>
<td>J308</td>
<td>0.0776</td>
<td>1020</td>
<td>384</td>
<td>0.5553</td>
<td>54.5</td>
</tr>
</tbody>
</table>
Summary of main improved cultivars for pitwood

*S. × jiangsuensis* CL‘J799’:
Average yield of wood aged 5 for pulpwood is 15.89 m³/ha, and the fiber content is 48.6%.

*S. × jiangsuensis* CL‘J903’:
Average yield of wood aged 5 for pulpwood is 20.22 m³/ha, and the fiber content is 51.55%.
Selection and breeding

Other *Salix × jiangsuensis* for pulpwood and pitwood
Selection and breeding

- Genetic improvement of wicker willow

  - *S. suchowensis* × *S. integra* CL‘Jw8-26’: shrub and female. Annual average yield of wickers is 29t/ha.

  - *S. integra* × *S. suchowensis* CL‘Jw9-6’: shrub and female. Average length of the wickers is 246.3cm. Annual average yield of wicker is 26.2 t/hm² and 12.3 t/ha for dry wickers.
Selection and breeding

- **Development of the research on high biomass:**
  - In 2000a, we obtained more than 40 clones with high yield, and their biomass is obviously higher than the traditional wicker cultivars.

![Yield of branches chart]

- 1. *psammophila × matsudana*
- 2. *suchowensis × integra*
- 3. Jw8 [?] 26
- 4. *integra × suchowensis*
- 5. Jw9 [?] 6
- 6. *integra × viminalis*
Breeding of Ornamental Willow

- For *arbor willow*, we did hybridization of *S. babylonica* × *S. alba*, and obtained 4 golden weeping clones: *S. × aureo-penduna* CL‘J841’, CL‘J842’, CL‘J1010’ and CL‘J1011’.
- All of the four clones are male, the young branches are drooping and golden in the dormant, and a great ornamental value is gained of weeping willow in winter.
For **shrub willow**, we have selected 5 ornamental shrub willows since 2000. They are mainly from the interspecific and intraspecific hybridization of *S. integra*, *S. turanica*, *S. argyacea*, *S. gracilistyla*, *S. sinopupurea*, *S. yapiniana*, etc.

- *S. turanica × S. leucopithecia* CL ‘J887’
- *S. dasyclados × (S. turanica × S. leucopithecia)* CL ‘J1037’
- *(S. babylonica × S. leucopithecia) × (S. suchowensis × S. leucopithecia)* CL ‘J1055’
- *S. suchowensis × S. leucopithecia* CL ‘J1052’
- *Salix suchowensis × S. leucopithecia* CL ‘J1050’
Selection and breeding

Other ornamental willow clones we conserved.
Selection and breeding

Other ornamental willow clones we conserved.
Selection and breeding

- **Breeding for tolerance**
  - Experiment and variety selected for **flooding** resistance
- From more than 50 clones, we have selected four improved clones: J308, J335, J1031 and J565. Even in the flood duration of about 60 days, all of them can grow normally.
Selection and breeding

- **Genetic improvement for saline resistance of willow**
  
  • Arbor willow: The results show that there is significant difference among the willow cultivars. *S. alba* (P318), introduced from the Danube basin in Romania, whose index of saline resistance is 2.5, but it is up to 70 when coming from dry areas.
Selection and breeding

- Shrub willow: We have selected 42 clones from the improved progenies by water culture. In the seashore with 0.1%-0.3% saline content of Dafeng County in Jiangsu Province, there are great differences among the clones, and the survival rates of three clones among them, specially 2345, are high and the average tree heights are more than 2m.
• **Cultivation technology**

  – Cultivation of strong seedling and classification
  
  • Technology of cultivation for wicker plantation.
  
  • Effects of plantation in different sites and tree species on the seedlings with different grade.

  ![Technical regulations for cultivation of Salix seedlings](image1)

  ![Salix seedling quality grading](image2)
Cultivation technology

- Several applied techniques for rapid propagation

Seedlings by spur cutting in spring and summer

Seedlings by spur cutting in spring

Seedlings by spur cutting in spring and winter
Planting density

- Research on planting density of different forest species
  - The planting density could be high for small or middle diameter willow for fiber wood. The planting space should be $2 \times 2$ or $2 \times 3/m$ for five-year rotation.
  - $3 \times 4$ or $4 \times 5/m$ is suitable for planting middle diameter for pitwood which can be rotated at the interval of 7–8 years.
  - For gardening, planting space is $4 \times 5/m$ with single line trees.
  - For multiple rows, the planting density should be no less than $4 \times 5/m$ to delay the rotation and avoid planting frequently.
Cultivation technology

• Tending management
  – According to our research, the compound pattern of combination of forest with crop before crown closure is feasible.
  – In the beach of the river and lake and the low wetland where interplanting cannot be carried out, we must plough and cut reeds after forestation, commit rotary tillage and irrigation after fertilizing in later spring and early summer and autumn.

Understory of the willow in the Hongze Lakeshore (Interplant for facilitating the growth of willow)
Cultivation technology

- Directing breeding
  - Breeding of pitwood plantation
    - For small diameter timber of Level 12-16, the planting space of *S. × jiangsuensis* CL‘J795’ can be 2m × 2m, and the yield is over $22.5\text{m}^3/\text{ha}$ in the beach of Yangtze River.
Cultivation technology

- **Pulpwood plantation**
  - This model is mainly used to put out middle or small diameter timber, and is mainly applied to plant in Yangtze River shoal or lakeshore where seasonal flooding usually occurs.
  - **Variety:** *S. × jiangsuensis* CL ‘J795’ and CL ‘J799’
  - **Planting density:** 1666 plants/ha - 6666 plants/ha
  - **Rotation:** 3~7 years
  - **Yield:** 24~34 m³ ha⁻¹ yr⁻¹

Yields of pulpwood and pitwood in Jiangsu, Anhui and Jiangxi

<table>
<thead>
<tr>
<th>Forest species</th>
<th>Clone</th>
<th>Site</th>
<th>Planting density</th>
<th>Rotation</th>
<th>Regeneration pattern</th>
<th>Yield (m³/ha·yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper-making raw material forest</td>
<td>J799</td>
<td>Higher plain of river and lake</td>
<td>1×2</td>
<td>3~5</td>
<td>Coppice</td>
<td>20~30</td>
</tr>
<tr>
<td></td>
<td>J903</td>
<td></td>
<td>1×1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>J172</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>J799</td>
<td>Flooding in the flood season</td>
<td>1×3</td>
<td>5</td>
<td>Coppice</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>J903</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>J172</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small diameter timber of pitwood plantation</td>
<td>J795</td>
<td>Impacted plain by rivers</td>
<td>1.5×3</td>
<td>5~7</td>
<td>Coppice</td>
<td>15~20</td>
</tr>
<tr>
<td></td>
<td>J194</td>
<td></td>
<td>2×3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cultivation technology

» Pulpwood yield of *S. × jiangsuensis*

Average increment of willow varieties in the beach of Fuchun River in Zhejiang Province

![Graph showing pulpwood yield of willow varieties](chart.png)
Cultivation technology

Fiber plantation of *S. × jiangsuensis* at Baguazhou in Yangtze River in Nanjing

Fiber plantation of *S. × jiangsuensis* in Hongze Lakeshore in Jiangsu Province
Cultivation technology

- Breeding for plywood timber
  - This cultivation model is mainly used to put out large diameter timber, and the bottomland is the suitable site. *S. × jiangsuensis* CL ‘J172’ and ‘J932’ are adaptive.
  - Practice as the our model can get 180.6 m³/ha of middle or large diameter timber and 56.7 m³/ha of middle or small diameter timber in 14-year rotation.
Cultivation technology

• Breeding of wicker plantation
  – Using S. suchowensis × S. intergra CL ‘Jw8-26’ and S. intergra × S.
suchowensis CL ‘Jw9-6’ for plantation, the planting space is 10 × 40/cm.
Or cutting in belt, the width of the belt is 40~60/cm with 10 × 20/cm
planting space and the belt distance is 1~1.5m. The yield is about 30t
ha-1 yr-1 at harvest.
Phytoremediation

– Effects of the wave breaks in Yangtze River
  From 1998 to 2005, we have studied the protection of willow forest on mitigating wave and reducing soil loss to Yangtze River Levee. Willow forest belt, 56m in width, can mitigate about 80% wave power in a fresh wind.
Phytoremediation of willow

- **Absorption of contamination**
  - Since 2003, we have studied the resistance and absorbing ability of *S. × jiangsuensis* varieties to heavy metal, especially cadmium. According to our research, *S. × jiangsuensis* CL‘J172' performed best.

---

*S. × jiangsuensis* CL 'J172' in different cadmium concentration solutions

<table>
<thead>
<tr>
<th>Items</th>
<th>Concentration of Cd(^{2+}) (×10(^{-6}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Cadmium concentration in stump plant (×10(^{-6}))</td>
<td>3.40</td>
</tr>
<tr>
<td>Enrichment coefficient</td>
<td>9.30</td>
</tr>
<tr>
<td>Times of Cadmium concentration increased</td>
<td>2.74</td>
</tr>
<tr>
<td>Dry weight of stump plant (g)</td>
<td>0.26</td>
</tr>
<tr>
<td>Absorption of Cadmium of stump plant (μg)</td>
<td>0.88</td>
</tr>
<tr>
<td>Times of the absorption of Cadmium increased</td>
<td>2.42</td>
</tr>
</tbody>
</table>
Phytoremediation of willow

- Phytoremediation of contaminated soil by fly ash
  - *S. × jiangsuensis* CL‘J172’ and 'J194'. Dry matter per kg of these cultivars can absorb 30.90mg F, 0.7037mg Hg and 1.7800mg Pb from the contaminated soil.
  - Hybridization of *S.babylonica* × *S. matsudana*, 1ha weeping willow can absorb 10 kg SO2 every month and the harmful elements in the abandoned land of mine.

- Cultivation in the saline soil
  - *Salix × Chuibao* CL‘J109’ is the hybrid of *S. babylonica* × *S. fragilis*, fast growing and has cold resistance. And it can grow very well even in the site with 3 saline content.
4 Project and development

• Research project
  - 7 Sci-tech Programs including 3 Key R&D Programs of National and Jiangsu Province
  - 3 Popularization Projects of Science and Technology aided with enterprises.

Key Scientific and Transform Technical Programs of Jiangsu Province

National Science and Technology Supporting Project
国家自然科技资源平台
林木种质资源平台技术标准
（试行）（标准文集）

2004年12月30日

植物新品种特异性、一致性和稳定性
测试指南 柳树

Guidelines for the Conduct of Tests for distinctness, uniformity and stability
willow
Extension area of *Salix × jiangensis* in China
5 Main achievements

• **22 improved willow**
  
  *S. × jiangsuensis* CL ‘J1-75’ and ‘J4-75’
  
  – Selected in 1982, and leading to winning the Third Prize of Science and Technology Advancement of Jiangsu Province

  
  – Selected in 1987, and the annual increment is up to 18~30 m³ yr⁻¹ ha⁻¹. Now, *S. × jiangsuensis* CL ‘J172’ and ‘J194’ are main plantation willow varieties in China.

  *S. × Chuibao* CL ‘J109’
  
  – It, with fast growth and cold and saline resistance, was selected in 1988. Even if at -40 °C there is no freeze injury, and it is one of the main forestation varieties of willow in the north China.
Main achievements

- **S. × jiangsuensis CL ‘J795’, and ‘J799’ and ‘J903’**
  - selected in 1997 with narrow crown, thin branches and straight stem, and suitable for high density plantation. Their yield are up to 30 m³/ha.yr in the beach of Yangtze River.

- **S. × jiangsuensis CL ‘J932’**
  - selected in 2007. Increment of plus plant is higher than the major cultivars, CL ‘J172’ and ‘J795’ in China. It is suitable for cultivating middle or large diameter timber.

- **S. suchowensis × S. intergra CL ‘Jw8-26’ and S. intergra × S. suchowensis CL ‘Jw9-6’**
  - selected in 1989. It has more flexible branches with high yield and rate of wicker, leading to winning the Third Inventive Prize of the Ministry of Forestry in 1990.
Main achievements

  - Four improved arbor cultivars for ornamental purpose selected in 1998. For they have tolerance to flood and cold, they are the major cultivars of garden willows in North China, East China and Northwest China.

  - All of the five cultivars with silver buds selected in 2004. Lots of big, pure white and plump buds scattered on the long flower branches evenly. They are good materials for making cut or dry flowers. Some cultivars have red branches in winter, so they have ornamental value on flowers and branches as the improved shrub cultivars for gardening.
Main cultivation models for industrial plantation of *S. × jiangsuensis*

- **Four practical cultivation models for industrial plantation**

<table>
<thead>
<tr>
<th>Land type</th>
<th>Selecting variety</th>
<th>Density and rotation</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach of Hongze Lake</td>
<td>J333, J795</td>
<td>1.5m × 1.5m; Planting by stem</td>
<td>Small diameter timber with high biomass</td>
</tr>
<tr>
<td>Beach of Yangtze River</td>
<td>J172, J795</td>
<td>1.5m × 2m; Planting by stem</td>
<td>Middle or small or small diameter timber</td>
</tr>
<tr>
<td>Coastal beach</td>
<td>Clones with salt tolerance</td>
<td>2m × 3m; Planting by stem or seedling</td>
<td>Middle or large diameter timber</td>
</tr>
<tr>
<td>Beach of ancient Yellow River</td>
<td>J172, J903</td>
<td>Rotation per 6 years or half to thinning; sprout regeneration</td>
<td></td>
</tr>
</tbody>
</table>
Main achievements

- **Literature published**
  - Monograph:
    
    *Breeding and Cultivation of Willow*, by Tu, Zhongyu.
    *Genetic Improvement of Broad-Leaved Tree*, by Tu, Zhongyu and Huang, Minren.
  - Published papers
    
    **Tu, Zhongyu** (the First Author, the same below)
    - Research on distant hybridization of *Salix × Chosenia*
    - Hybridization and heterosis of willow
    - Breeding and selection of four arborclones of willow
    - Research on variation factors of willow plant type
    - Preliminary research on the genetic variation of photosynthetic properties of willow
    - Cluster analysis of willow hybridization
    - Research of main composition of quantitative traits of willow hybridization
    - Genetic correlation between branching characteristics and trunk growth of willow hybridization
    - Breeding of willow clones, J1-75 and J4-75, with fast growth
    - Multipurpose forestation and breeding of willow
    - Dynamic analysis on growth of willow
    - Variation of relational characteristics and selection of the index of wicker willow
    - Variation and selection of the clones of *S. babylonica × S. fragilis*
    - Breeding of *S. suchowensis × S. intergra* CL‘Jw8-26’ and *S. intergra × S. Suchowensis* CL‘Jw9-6’
    - Breeding of golden weeping willow
Main achievements

**PAN, Mingjian**
- Research on genetic variation of fiber characteristic of willow
- Genetic improvement and cultivation of willow

**GUO, Qun**
- Strong seedling and cultivation of willow clones
- Investigation of the growth and adaptation of seven willow excellent clones introduced in different areas
- Research on high-yield cultivation technique of industrial plantation of willow clones on beach
- Effects of breeding ways on seedling growth and quality of willow clones
- Afforestation and management of willow clones in the beach of the lower Yangtze River
- Research on the comparison of the growth, stem type and applicability of new willow clones for industrial plantation
- A study on the density of willow clone plantation growing on beach
- A study on the growth of *Salix × jiangsuensis* CL ‘J172’ and CL ‘J194’ plantation
- Research on the experiment of seedling density on external beach of Yangtze Dike of *Salix × jiangsuensis* CL ‘J172’ and CL ‘J194’
WANG, Baosong

- Breeding of excellent arbor willow clones for pulpwood
- Study on genetic variation of tolerance to water stress of willow hybrids and clones
- The selection of willow excellent clones for pitwood
- Genetic variation of wood basic density of willow hybrids

SHI, Shizheng

- Investigation on bioenergical and industrial chain of willow
- Prospect on breeding of bioenergical forest of shrub willow
- Seedling growth determination of the primarily-selected *Salix* clones of exotic origin
- Application types in garden of willow and its improvement
- Introduction and domestication of willow germplasm with high resistance from UK and US
- Construction of Fast-growing and High-yielding Willow Forest and Its Utilization
WANG, Youliang

- Study on phytoremediation of Cadmium contaminated water-body by willow seedlings in solution culture
- Cadmium absorption characters of arbor willow (*Salix* sp.) in solution culture
- Utilization of willow (*Salix* sp.) in phytoremediation
- Effect of Cadmium (Cd\(^{2+}\)) on the development of cuttings of 4 arbor willow clones under water culture

HAN, Jiefeng

- Studies on variation within tree of wood density in arbor willow clones
- Growth course analysis of three clones of *Salix × jiangsuensis*
Main achievements

• Great social and economic benefits of the willow research in JAF


- More than 4000 ha of timber plantation and ecological forest are constructed in the area of Dongting Lake and Poyang Lake, and the annual average increment is more than 22.5 m³/ha.

- Every year, we provide the study materials and technological service for a dozen research, extension institutions, and more than 20 production units through the whole country.
Main achievements

• Awards
  – We have gotten 15 important awards, including the Second Award of the State Invention, the First Award of the Agricultural Sci-tech Progress of the State, the Second Award of the Sci-tech Progress of Jiangsu Province, the Second Prize of the Sci-tech Advancement of the Ministry of Forestry.
More information, please browse our homepage!

http://www.jaf-dos.cn

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<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>沈思武先生开展柳树资源收集和良种选育工作。</td>
</tr>
<tr>
<td>1972</td>
<td>组建柳树课题组，开展亲本测定，杂交技术和子代测定等研究工作。</td>
</tr>
<tr>
<td>1980</td>
<td>柳树良种研究被列入国家攻关项目，在全国15个省市区开展试验与示范。</td>
</tr>
<tr>
<td>1990</td>
<td>选育出的苏柳172和苏柳194两个无性系获得国家发明二等奖。</td>
</tr>
<tr>
<td>1998</td>
<td>成立柳树研究所。</td>
</tr>
<tr>
<td>2004</td>
<td>开始建设中国柳树种质资源保存圃。</td>
</tr>
</tbody>
</table>

至2006年，承担国家重大项目8项，省级重大项目8项，选育出用材、建筑和观赏等柳树良种22种，研究了多种工业用材林业技术。苏柳良种已经成为全国最主要的柳树造林品种，在21个省、市、自治区推广80多万亩，发挥了巨大的社会经济效益，获得省级以上科技成果奖励7项，出版4部专著。

柳属遗传改良

以常规育种为主，结合生物技术，开展柳树品种改良，以生长性状和观赏性状为主要改良目标，结合纤维品质、抗性与适应性等品质改良，选育适于造纸、生物质能源、人造板、柳编工艺、观赏、绿化等新品种。

柳树高效栽培技术

针对不同品种、不同立地条件，研究栽培措施对柳树新品种产量与品质的影响，通过建立最优栽培模式。

柳树种质资源保护研究

到2006年，累计收集了44个品种400多产地的亲本材料，其中乔木柳250多个，灌木柳150多个，基本上包含了目前有经济利用价值的主要种类。
Thanks for your attention!