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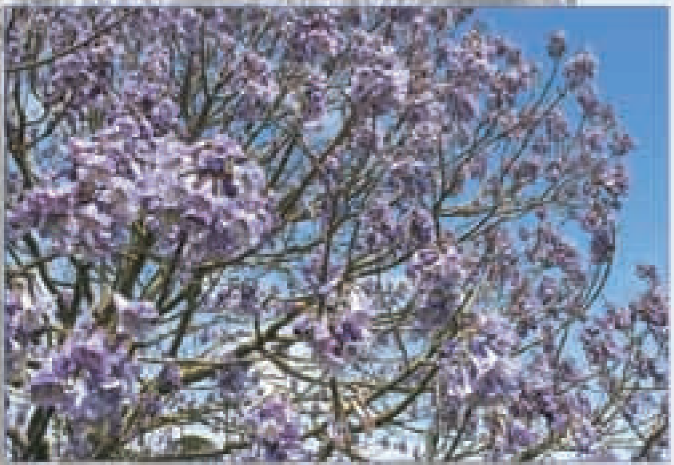
Paulownia

I. L. Barton, I. D. Nicholas
and C. E. Ecroyd



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Paulownia

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Rotorua, New Zealand
2007

FOREWORD

Paulownia species have been regarded as amenity trees in New Zealand for more than 50 years. Following the publication of an article by Alan Meyer in the *New Zealand Farm Forestry Journal* (1980), Ian Barton, a forestry consultant, became interested in the potential of *Paulownia* as a productive forest tree. Ian and his wife Jan set up a nursery on their Hunua property near Auckland, and Ian published a newsletter, *Paulownia Ne*ws, to keep clients informed about his nursery activities.

In 1989, Kevin Avery of New Plymouth circulated a paper describing the virtues of *Paulownia* through the national Rural Delivery service. Although staff at the New Zealand Forest Research Institute had been aware of the market potential of *Paulownia* for many years, only a small number of plants had been established by researchers in New Zealand and little was known about preferred species or management systems. The Paulownia Action Group was set up in 1989 to promote evaluation of the species under New Zealand conditions. A visit to China by Ian Barton and Ian Nicholas in 1991 resulted in better understanding of the genus. As interest in *Paulownia* declined, probably as a result of poor performances of new plantations, the Action Group went into recess in 1996.

Support from the MAF Sustainable Farming Fund, combined with existing Action Group Funds, was obtained to produce this Handbook. This Handbook brings together information gathered during the Paulownia Action group era. It shows that *Paulownia* can be regarded as a multi-purpose tree with potential for use as a short-rotation timber species when grown under specific New Zealand conditions.

The input of the Action Group members, in particular Jim Peele who has facilitated the production aspects of this Handbook, MAF Sustainable Farming Fund, and Ensis is very much appreciated. Comments on the text from Dr Mike Wilcox and Dr Tony Shelbourne, Dr Jim Douglas, Professor Warwick Silvester, Dr Luigi Gea, and Elizabeth Miller, valuable editing from Dr Ruth Gadgil, and the input of Teresa McConchie for her graphics expertise are all most appreciated. We are grateful to Dr Alan Dickson for the drawings in Fig. 19, Paul Wynen for the photos of *P. kawakamii* in Fig. 24, Dr Jacqueline Bond for help with the photos of leaf hairs (Fig.20a and b), and Ian Barton for specimens.

PREFACE

HISTORY OF THE PAULOWNIA ACTION GROUP

In 1989 the New Zealand Farm Forestry Association set up the Paulownia Action Group under the auspices of the NZ Tree Crops Association and the NZ Farm Forestry Association. The purpose was to provide landowners with an independent source of information about *Paulownia*. Chaired by Ian Barton, the Group was active until 1996, and was responsible for many newsletters, information handouts, and seminars. It also assisted in the setting-up of eight species trials in different parts of New Zealand.

At its peak the Group had about 270 members. Newsletters contained information about growers' experiences, and also research reports from the New Zealand Forest Research Institute Ltd and Waikato University. Following a special meeting in 1996 the Group went into recess. Ian Barton and John Gourley assumed responsibility for use of accumulated funds to publish a summary of knowledge about the growing of *Paulownia* in New Zealand. With the aid of additional funds obtained from the Ministry of Agriculture and Forestry Sustainable Farming Fund, this Handbook has been prepared as a resumée of the findings of the Paulownia Action Group.

PAULOWNIA ACTION GROUP

Objectives:

- To disseminate information about *Paulownia* as a timber/multipurpose tree to all interested parties
- To set and co-ordinate research guidelines
- To ensure the survival of gene pool sources
- To co-ordinate the activities of groups and organisations interested in *Paulownia*
- To co-ordinate research and marketing information from overseas growers and users.

The Original Committee

Chairman: **Ian Barton** (Farm Forestry Association)
Secretary/Treasurer: **Peter Hayward** (Co-opted member)
Members: **Ian Nicholas** (New Zealand Forest Research Institute Ltd, Rotorua)
Jim Peele (Tree Crops Association)
Graeme Rogers (New Zealand Forest Research Institute Ltd, Christchurch)
Fiona Ede (University of Waikato)
Jim Douglas (Ministry of Agriculture and Forestry)
Tony Firth (FRI Co-opted member)

Other major contributors to the Committee over the years were **John Gourley, Errol Hay, Wade Cornell**, **Shem Kerr,** and **Warwick Silvester**.

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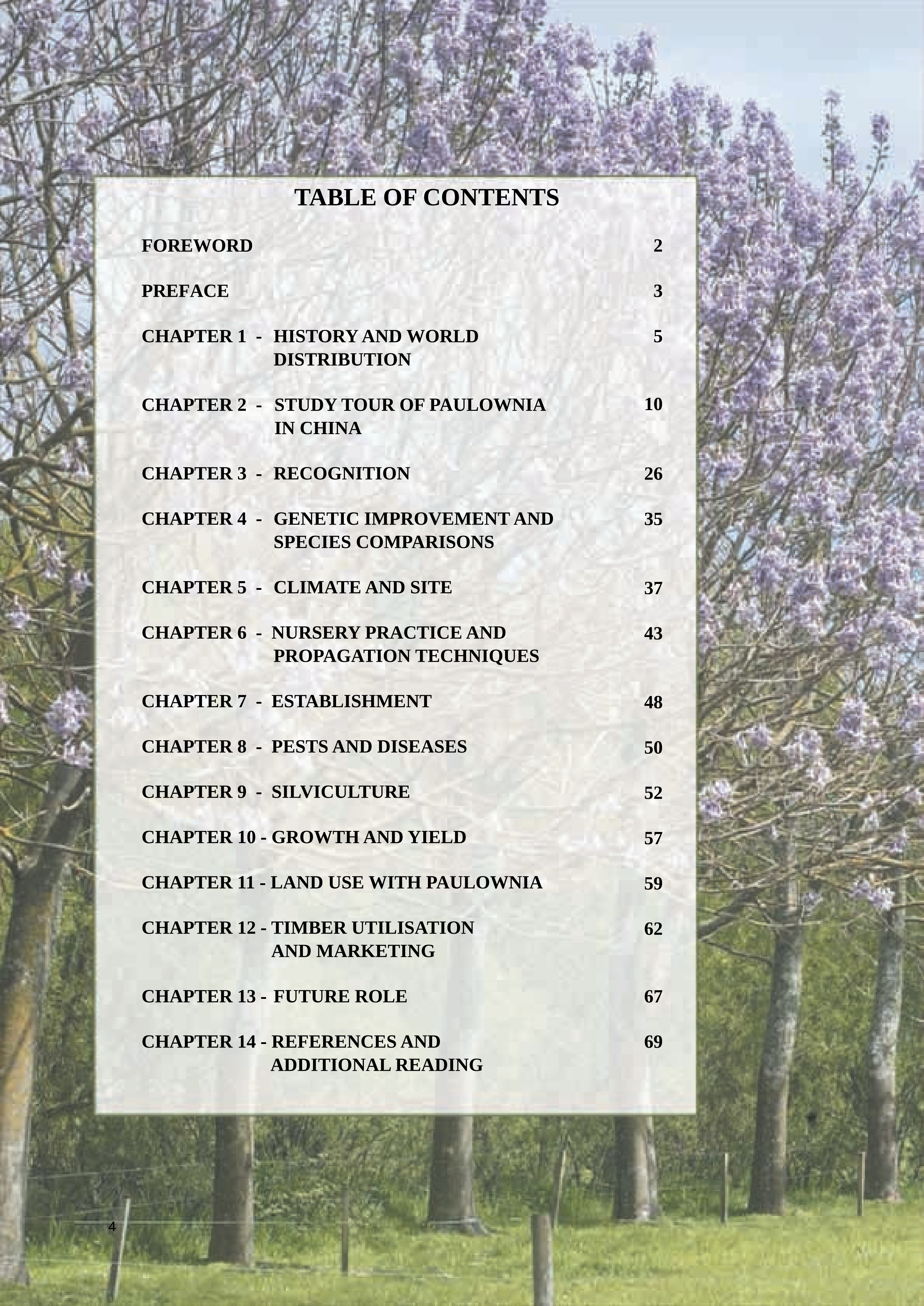

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CHAPTER 1 - HISTORY AND WORLD DISTRIBUTION

The genus *Paulownia* is native to China. Two of the 17 listed species, *P. fortunei and P. fargesii*, extend into Vietnam, while the former also extends into Laos. *Paulownia* has been cultivated for at least 2000 years, and there are now few known examples of natural occurrence.

In the history of trees used by man, probably more is known about *Paulownia* than about any other genus. The earliest known record is in a book called *Erh-ya*, thought to have been written in the third century BC by a disciple of Confucius. This contained a reference to Yung-t'ung-mu (wood of the glorious *Paulownia*). Other references to *Paulownia* in very early times are listed by Zhu *et al.* (1986).

In AD 1049 Ch'en Chu produced a treatise entitled *T'ung-p'u* (A Repertory of Paulownia). This shows that the Chinese people had a profound knowledge of *Paulownia* as a cultivated tree almost 1000 years ago. The history of the genus, methods for propagation and cultivation, habitat and origins of the best varieties, pruning and harvesting, utilization, as well as tales, folklore, and poems about *Paulownia* were all described in *T'ung-p'u*. Ch'en Chu recognised two “species”. One was Pai-hua T'ung, the white flowered *Paulownia*, which had coarse-grained wood, large smooth rounded and elongated leaves, white flowers with pink centres, and oblong fruit up to 3 cm diameter. The other was Tz'u-hua T'ung, which had purple terminal flowers resembling those of *Wisteria*, finer-grained wood, angular, hairy leaves, and a smaller, nipple-like fruit with a pointed apex. These descriptions resemble those for *P. fortunei* and *P. tomentosa* respectively.

A significant publication from medieval times was *Pen-ts'ao-kung-mu*, written by Li Shih-chen. Li described *Paulownia* wood as light, resistant to insect attack, and useful for furniture, beams and pillars. He may have been the first to record the medicinal properties of the genus, giving eight prescriptions for the use of leaves, bark and flowers.

CURRENT DISTRIBUTION IN CHINA

Figures 1 - 4 show the present distribution in China of the main *Paulownia* species, (based on figures of considered natural distributions presented by Zhu *et al.* 1986). The boundaries between wild and cultivated populations have become very blurred; authorities no longer make a distinction between the two.

Figure 1: Distribution of *P. tomentosa (from Zhu et al. 1986).*

Figure 2: Distribution of *P. fargesii. from Zhu et al. 1986)*

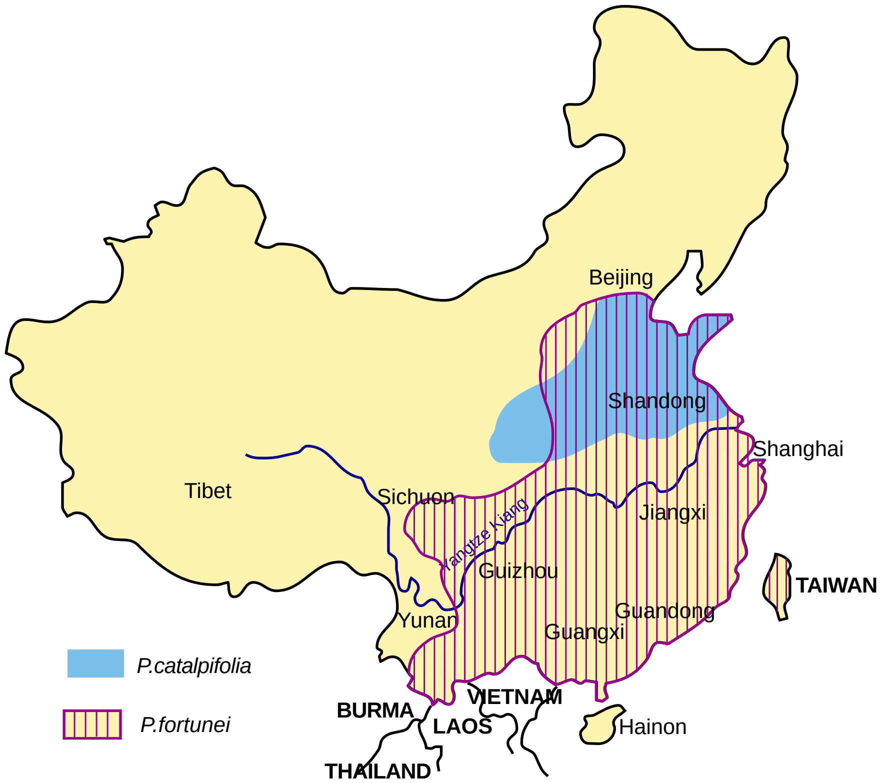


Figure 3: Distribution of *P. catalpifolia, P. fortunei*.

Figure 4: Distribution of *P. elongata, P. kawakamii*

WORLD DISTRIBUTION

Paulownia was probably introduced into Japan and Korea about 1,000 years ago by Buddhist monks. It has since become naturalised in both countries.

The earliest European record of *Paulownia* was published by Kaempfer in 1712. From this time onwards the genus began to appear in other parts of the world, the main attraction being its beautiful flowers. Many of the early records were lost but Hu (1959) records the following dates for probable first introductions:

Holland and Belgium	1830
France	1834
England	1838
USA	1844
Austria	1863 (flowering)
Rome	1888 (flowering)
Australia	pre-1922

INTRODUCTION AND DISTRIBUTION IN NEW ZEALAND

The oldest known *Paulownia* tree in New Zealand is a specimen of *P. tomentosa* located at Clifton, near Takaka in Golden Bay. It was planted about 1860 (Burstall and Sale,1984) and has probably re-sprouted from a stump at least twice. A specimen of *P. elongata* in Isel Gardens, Stoke, Nelson, may also have originated from an early introduction.

The genus is now found throughout the warmer parts of the country. Seed of *P. elongata* was imported from China about 1950 and the progeny was planted in parks and gardens in Hamilton, Auckland and Christchurch. Since 1986 seed from selected Chinese provenances of *P. tomentosa, P. fortunei, P. elongata, P. fargesii* and *P. catalpifolia* has been brought into the country, (Note that research on several of these seedlots has shown that species names are incorrect; in particular *P. catalpifolia* may not be present). *P. kawakamii* is also present in some arboreta.

Paulownia in New Zealand was originally used for amenity planting only, until the mid-1980s when interest in its forestry potential increased. Selected seed, imported from China, was used to establish plantations throughout the country until the early 1990s. Many of these plantings failed for one or more of the following reasons:

- Spring frosts were too frequent
- Summers were too dry
- Soils were too heavy (too much clay/moisture)
  Releasing and early form-pruning were neglected.

In 1998 it was estimated that the total area of well-established *Paulownia* did not exceed 100 ha nationwide, and that the age of most of the trees was then less than 10 years (J. Peele *pers. comm*.). The total planted area has since declined due to landuse pressure and a return to horticulture. There are still a number of small *Paulownia* plantations in the warmer northern and/or coastal parts of the country. Since 2000 there has been a small resurgence in interest resulting in a few more hectares planted, mainly in Northland.

Figure 5: Plantation of Paulownia near Te Puke, Bay of Plenty.

Figure 6: Ornamental *Paulownia* in a farm paddock near Ohinewai, Waikato

Key Points

- *Paulownia* has a long history of cultivation in China
- The distinction between wild and cultivated populations in China is blurred
- *Paulownia* has been established in New Zealand since 1860
- Imported seedlots have often been incorrectly identified
- A few successful plantations have been established in New Zealand, but many attempts failed.

Additional reading:

Hu (1959)

Burstall & Sale (1984)

Zhu *et al.* (1986)

Meyer (1980)

CHAPTER 2 - PAULOWNIA IN CHINA

The most important published literature on *Paulownia* originates from China. To help interpret the Chinese information and to observe its relevance to New Zealand conditions, Ian Barton and Ian Nicholas, with support from New Zealand's Ministry of Foreign Affairs and Trade, were fortunate enough to visit China for a 17-day study tour in June/July 1991. Hosted by the Chinese Academy of Forestry (CAF) (Professor Zhu and Dr Xiong), the tour covered from Beijing south-west to Xian, east to Shangqui and Yanzhou, and south to Nanjing, Tongling, and Hangzhou. Most of these places are on the great plain, the area of China where *Paulownia* is the major species planted in agricultural areas. Other than *Paulownia* the main trees seen were *Populus*, *Robinia* and *Fraxinus*. The study tour helped put *Paulownia* into perspective for the New Zealand situation and much of the detailed information collected has been used in the relevant chapters in this handbook.

Figure 7: Seven year old *Paulownia* in combination with wheat

A very important part of research work in China is the friendship and co-operation between individual scientists. CAF relies on contacts with other scientists at Provincial, Prefectural, and County level for much of its work. Each County has its own Forestry Bureau with some 50 - 60 staff that mostly advise villagers. Usually each township has a forestry technician. How trees are regarded in a township or village will often depend upon the attitude toward trees of the township's Chairman. Some like them and some don't.

Overview of the places visited in 1991

Near Beijing, poplar is the most important rural tree but *Paulownia* becomes more important further south where the climate becomes a little drier. Most of the trees in these areas are *P. elongata*. Other tree species are *Sophora* and *Robinia* with a few poor conifers, mostly *Sabina*, on hillsides.

Going south from Beijing the land is very flat with walled villages surrounded by their fields. Near the villages are many older trees while in the fields plantings are relatively recent – mostly poplar. Fields are divided into strips and the village council allocates these to families; the size of a holding is dependent upon family size. Main crops grown are winter wheat, followed in summer by corn, cotton, or peanuts. There are also many small plots of vegetables: tomatoes, beans, peppers, etc.

Figure 8: Village side planting of *Paulownia*

Some of the rural areas beside the railroad track near Xian have few trees apart from the villages where *Paulownia* is important. Here too the area is flat, but comprises large river terraces, not plains. Most of the *Paulownia* is quite young, about 7 to 8 years old, for in the immediate past these villages and fields had no trees at all. The *Paulownia* are *P. elongata* and hybrids *P. tomentosa* x *P. fortunei*. Other tree species are poplar, *Sophora* and persimmon. Nearing Xian the amount of *Paulownia* increases dramatically; there is almost no other species of tree. However the standard of silviculture appears to be low with tree form generally poor except for a few small plantations. Spacing is generally closer than expected, about 3 - 4 m.

Further south, near Tongling which is part of the northern edge of the subtropical region of China, it is hillier and the landscape and plant species are different from the plains. The landscape looks more like New Zealand, as does the forest, although 80% of plant species are still deciduous here. South of Nanjing there is a change from winter wheat growing to rice, with usually three crops being grown annually. Many paddies are seen on either side of the train. Little *Paulownia* is seen until approaching Tongling because most of the area is low-lying and wet. The soil also appears heavier. The main roadside tree is Oriental plane (*Platinus orientalis)*. We also saw several small plantations of Chinese fir (*Cunninghamia lanceolata*) and pine (mainly *Pinus taeda*).

There are many plantations and roadside shelterbelts of *Metasequoia glyptostroboides* which is very straight compared to the form of trees grown in New Zealand.

It was unusual to find places where trees are not planted along both sides of the road. Poplar is probably more used for this than *Paulownia*, while *Salix* is also used. In the North China Plain our route passed through old riverbeds and flood plains of the Yellow River. The former are often several kilometres wide. In areas with water tables higher than about 3 m, poplar is preferred to *Paulownia* so there is often an abrupt change from one species to the other. *Salix* is seen where the watertable is higher still. Where it comes to within about 50 cm of the surface there are usually no trees. Species mixtures do occur but are not common and one species usually dominates.

Agroforestry and the Forest Net

For centuries *Paulownia* has been used extensively as an agroforestry tree in the cropping areas of China. However, during the last 25 years management practices have changed in the light of a major research programme.

Observations that *Paulownia* can have a beneficial effect on crop yields have given impetus to the development of a major "Forest Net" system (Zhu *et al.* 1986). The Forest Net is a grid of single-row shelterbelts, consisting mainly of *Paulownia* and *Populus* species with *Ziziphus jujuba* and *Ulmus* species also used in some localities (Zhu *et al.* 1986). Many counties on the plains of the Chang Jiang (Yangtze) and Huang He (Yellow) Rivers are now covered with the Forest Net. A good example of this can be seen around the city of Yanzhou in Shandong Province where the net was first established in 1964. There is now a total area of 45,000 ha with 3500 km of shelterbelts, about half of the 350,000 shelterbelt trees being *Paulownia*. In the county of Hangzhou the main shelter planting is poplar, which is better for wind resistance, with *Paulownia* forming the more extensive intermediate breaks. When the Forest Net was first set up villages, roads etc were moved in order to get the shelter lines straight. The land was then divided into individual net cells, each with an average area of 7 ha. Within these cells are grown wheat, maize, soybean, tea, *Fraxinus* (coppiced for basketry and staves), *Salix* (coppiced for basketry), grapes, apples, and other fruit, jujube, *Amorpha fruticosa*, and many different types of vegetables.

Prior to establishment of the Forest Net, agricultural production in Hangzhou County averaged 1.5 tonnes/ha. It is now 15 tonnes, a 10-fold increase. There are many reasons for this but most are linked to microclimate improvement brought about by the shelter provided by the shelterbelts of the Net. Wind speed is reduced 25 - 40%; summer air temperature is reduced 1.1 - 1.3 ^{o}C; winter and autumn air temperature is increased 1^{o}C; evapotranspiration is decreased 15 - 25%. Before the Forest Net was established there was a 19-day period of hot dry winds, just before harvest, which seriously affected productivity. The forest net has reduced the wind effect to 3 days. This county has richer soil and better management than many other places. It also has full irrigation. All of this results in higher productivity. The fact that maize growth was further ahead here at the time of our visit than in other places visited, reflected this.

As well as the marked increases in crop production, the County is now self sufficient in timber with a stock of 495,000 m^3. Production from the first rotation was used to meet farmers' needs in this timber-deficient area but from 1990 they had timber to export, with almost 10 000 m^3 of logs going to Japan along with 2 000 m^3 of veneer from the peeling plant in Yanzhou.

When the combined effects of the wind and temperature changes noted above are compared for the region as a whole there have been increases in wheat yield of 6 - 23%, millet yield increases of 20% and maize increases of 7.5 - 17%. However cotton and soybean yields were not affected and productivity of sesame and sweet potato actually declined slightly. The latter are evidently crops that can only be grown with *Paulownia* when the trees are young or planted at low density.

Paulownia is not used in association with pastoral farming in China because it does not grow in areas where extensive animal grazing occurs.

Figure 9: Example of the forest net using *Paulownia*.

Paulownia nursery production

Yanzhou Forest Research Institute was established in 1979 on 20 ha with a staff of 13. It undertakes work for CAF and the provinces and cities of the region with extension work which focuses on the plains area.

Paulownia work started here in 1979, and has been supported by CAF and the International Development Research Centre (IDRC) since 1980. Along with poplar, *Paulownia* is considered to be very important on the plains area. The major emphasis is on tree breeding, mainly the production of superior clones reselected from earlier testing. They do some tissue culture work as well as using seedlings from superior trees. In April 1991, they planted into the nursery 8900 tissue culture plantlets and 1200 seedlings comprising 86 clones, plus root cuttings. Surprisingly they have a bad weed problem in the nursery as they can't get people to weed because spring is the harvest and drying time of the winter wheat crop and everyone is very busy with this. In July growth of the above material was just beginning (plants 20 - 40 cm tall). They are planted out at 3 -5 cm tall and were expected to be 3 -5 m tall by the end of the growing season. At the time of our visit seedlings were not as big as the plantlets.

Figure 10: *Paulownia* nursery production

Figure 11: *Paulownia* research plantation

Paulownia establishment and silviculture

A replicated clonal trial of *Paulownia* planted in 1986 comprising five species with 118 clones was also seen at Yanzhou. These have been fertilized twice annually and irrigated four times annually since planting. Weeding and under-cultivation is also carried out with crops grown under the trees where possible. Pruning commenced in the stand at age 3 but no trunk extension work was done because they were looking to discover the natural form of the *P. elongata*. Some clones had excellent form with good natural extension to 8-9 m.

Research into the drought resistance of the species is conducted at this station. Results to date show that from best to worst they *are: P. tomentosa, P. elongata, P. kawakami, P. fortunei, P. catalpifolia. Paulownia fargesii* has not been tested, as it will not grow in this area (Miss Song pers. comm.).

A *Paulownia* plantation was visited at Baqiao, SE of Xian city. In this area *Paulownia* is growing everywhere, mostly young trees and as a rule not particularly good form. The area of the plantation visited is about 10 ha, which is unusual as plantations are not common. However this one is located on an area of land previously considered unproductive. It is managed by two families who live on the site. The trees were planted in 1984 as 3-m poles and were spaced at 6 x 8 m. Subsequently this was considered to be too wide and in 1985 poplars were inter-planted to reduce the spacing to 6 x 4 m. However this did not work as the poplars were suppressed and had no value except as fuelwood. In the first year a crop of melons was grown between the trees and in the two subsequent years winter wheat. During this period the stand was irrigated and fertilized.

Pollarding (the Chinese call it trunk extension) was done at planting and repeated annually for 3 years in order to get a straight trunk. The species in this stand is a P. *tomentosa* x *P. fortunei* cross but is not a superior clone because these were not available when the stand was planted. The farmer also brought in some trees from other sources. The growth rate was excellent. At age 7 the mean diameter was 30 cm, with the largest trees about 34 - 38 cm. The present intention is to harvest at age 10.

Annual increment has progressively reduced through the 7-year period.

- 1986/87 10 cm/yr
- 1987/88 8 cm/yr
- 1988/89 2 cm/yr

Assuming 2 cm to be the mean annual diameter increment from now on, the average dbh at age 10 will be about 36-38 cm. The Chinese consider the 10 cm increment of the early years to be too fast and state it was probably due to the intensive crop management giving a massive boost to growth. Soon after cultivation ceased the growth rate fell away. Other factors which could have affected growth are excessive pruning, soil factors and crown closure. More fertilizer was applied in the sixth year but there was no measured growth increase.

The Chinese suggest that pruning is best done in three lifts, commencing about year 3. They recommend not taking off more than one whorl initially but can take off two at later lifts. Pruning seems to reduce growth rate. It was noted that epicormics had developed on many trees. These are removed before they get too large.

The target trunk is 6 m long and this lower log is sold. Any small logs above this will be used by the farmer, although most of the upper limbs are used for fuel.

We visited the Weihi Experimental Station near Xian in Shaanxi Province. It was founded in 1953 and consists of 57 ha, including a 12 ha nursery. Major research is with *Paulownia* and poplar, with emphasis on tree breeding and insect and disease control (e.g., cicada damage). The station is located in a lowland area and can flood. Other species which are worked on are *Robinia, Fraxinus, Sabina, Sophora*, and *Toona*.

A *Paulownia* block seen was planted in 1987 with 13 clones set out in random blocks with four replicates and four plots. The material was hybrid *P. tomentosa* x *P. fortunei*. One of the clones being tested is YH 1 from Honan. This trial does not have a pure species as a control. At planting the trees were 4-5 m tall and were spaced at 4 x 4 m. Stem extension techniques were used at time of planting. This technique seems to be practised only with *P. elongata* and the *P tomentosa* x *P fortunei* hybrid. It consists of cutting the top 40 cm off the pole at planting and, as already noted, can be repeated for 2 - 3 years thereafter. New shoots are reduced to one. Lateral pruning is done each autumn. The trees have now been pruned to 3.5 - 5 m, with one more pruning to remove two whorls scheduled. Cropping has been done each year with winter wheat, the 1991 season being the last crop. The stand has been fertilized and irrigated each year. The scientists involved now consider that 6 x 6 m spacing would be better for *Paulownia* in order to get best growth. This also means that other crops can be grown underneath for longer with wider spacing. The stand data at age 4 were:-

- Height 9 -10 m
- Mean dbh. 20 cm
- Max. dbh. 25 cm
- M.A.I Differs between clones (Av. = 5 cm)

Nearby was another plantation, a plus-tree collection of *Paulownia*. It was spaced at 4 x 4 m with 44 clones in the collection, 16 being *P. tomentosa* and 28 *P. fortunei*. This stand was established by grafting branches of plus trees from various regions onto local rootstock, which means they flower earlier. This is a gene bank and is now 1 year old, grafted in 1990 and planted out in 1991 with the originating province selecting the individual plus-trees. The under-crop was soybean.

Grafting is done in late winter/spring when the sap is just beginning to move, but before the flowers open. They take a whole flower stem and cleft graft this on to a 1-year-old root which is cut off about 5 cm above ground level. They bind the graft well and then heap earth around the graft after binding.

The third trial seen at Weihi was planted at 6 x 6 m in 1984. There were 10 clones with four replications in four blocks and *P. elongata* was used as a control. The two best clones were Shantong No. 1, and Shantong No. 2, both *P. tomentosa* x *P. fortunei*. The mean diameter was 30 cm and height 12 - 15 m. There was a significant difference between the clones with No. 1 being the best. The soil in this region is 60 cm of sandy loam on sand and is old river bed.

Minquan County, near the city of Shangqiu is regarded as the home of agroforestry and one of the first areas in China where Paulownia agroforestry began. The County is about 25% forested, double the national average, and this was very evident. Trees are everywhere, mainly *Paulownia* but also poplar, *Robinia*, etc. Planting at the village of Wanqiau was inspected where five trees remain of the original *P. elongata* planted in the modern phase of *Paulownia* forestry. These 27-year-old trees were planted in 1964 when the village did its first planting of 27 ha of *Paulownia* and crops. The five trees are protected but all the others were felled at age 10. The individual volume of the five protected trees is about 4.6 m^3. Diameter of tree measured was 96 cm (at 1.3 m) (Figure 12). Some butt damage was noticed but this is not considered a problem as *Paulownia* appears to be very good at compartmentalising damage. *Paulownia* are now on the third or fourth rotation in this village.

Figure 12: 27-year-old *Paulownia*, part of a reserve, 96 cm in diameter (at 1.3 m)

At the nearby town of Jiao Tong we saw many different agroforestry combinations, the total area under cultivation being 200 ha. Annual crop yields, mainly winter wheat and maize (two crops a year are grown), are 6000 kg/ha which is worth 1,800 yuan (NZ$600). *Fraxinus chinesis* is commonly coppiced and *Fraxinus*/crops or *Paulownia/Fraxinus*/crops are combinations which are commonly seen. The *Fraxinus* yields a crop of poles every 3-4 years. These are ca 3 m long and 3-4 cm diameter. They are used for tool and broom handles, supports, staves and furniture (similar to cane furniture). The coppice stools also produce 1-year shoots which are used for basket weaving. *Fraxinus* can be coppiced many times before the stool has to be replaced and each stool produces two to three poles. The average yield of poles is 6750/ha and they are worth 2 yuan each, with an annual return of about 4,500 yuan (NZ$1,500).

Figure 13: *Paulownia* mixed with a number of crops

Another crop combination seen was *Paulownia*/grapes/crops. Grape yield is 3 tonnes/mu (15 mu/ha = 666.7 m^2). This is worth 27,000 yuan/ha (NZ$9,000/ha). There are two variations of the combination:-

- grapes most important, crops secondary.
- grapes and crops equal in importance.

Grape production has declined in recent years because over-production of wine has meant some vines have been taken out. The wine produced is of good quality.

Paulownia/apples/crops was another combination seen. Here income varies because of fruit tree age. Trees begin to bear at age 5-6 and peak at age 15. Yield from 15 year plus trees is 90 tonnes/ha, worth 90,000 yuan (NZ$30,000). Apple tree stocking is 300/ha. Peaches, pears, and plums are also used in this combination. Income from *Paulownia* is calculated on a mean stocking of 30 - 45 trees /ha, the annual increment of each tree being worth 20 - 30 yuan. At age 10 one tree is worth 200 - 300 yuan and the value per hectare is 6,000 to 13,500 yuan. The annual yield per hectare from *Paulownia* thus ranges between 600 and 1,350 yuan (NZ$200 - 450).

There are over 0.7 million farmers in Minquan County. The town of Jiao Tong is richer than average because it produces all of its basic food requirements and has large surpluses for sale. The 1986/87 income per head of population was 1,000 yuan (NZ$333). This has now dropped slightly because of reduction in area under grapes.

NOTE: *Paulownia* and ginseng are not grown together because it is too cold for *Paulownia* in ginseng-growing areas.

At another village we saw a clonal trial. *Paulownia* poles were planted in March 1991, in large holes (1 x 1 x 1 m). There were 24 clones in random design with five replications and three trees per replicate. Spacing was 5 x 10 m. A protective row of *Paulownia* was planted around the edge of the plot, survival to date being 99%. Cotton was growing under the *Paulownia*.

Close by was a 0.24 ha *Paulownia* nursery with plants spaced at 1 x 1 m. Sprouted root cuttings were put into the ground in March 1991. They had grown to between 20 and 100 cm tall in 4 months. All were from the same clone. Adjacent to this was an area of larger poles, aged 3 years. This was a testing area for witches' broom. There were five trees each of 200 clones from several species and provenances. In year 2 badly infected trees were removed. Note that witches' broom is infectious during the wet summer months. Cotton was the main crop here. Also sesame, melon, maize, and peanut crops are grown with *Paulownia*.

Further south we visited Tongling Forest Farm which is operated by the city and located on its outskirts. It is also one of the 10 experimental stations run by the CAF and is important because of its location on the north edge of the sub-tropical area. It was established in 1978 and *Paulownia* has been grown since 1979. There are two major projects; tree breeding and agro-forestry.

We were shown several agroforestry combinations:-

- *Paulownia*/magnolia/lily (magnolia for traditional medicine, and the lily is eaten)
- *Paulownia*/large bamboo
- *Paulownia*/small edible bamboo
- *Paulownia*/tea (*Paulownia* spaced at 5 x 10 m. and tea at 2.5 x 1.5 m.)
- *Paulownia*/Chinese fir
- *Paulownia*/nursery plants (for city parks, etc)
- All the *Paulownia* in these models is 11 years old except in the edible bamboo combination where it is 3 years old.

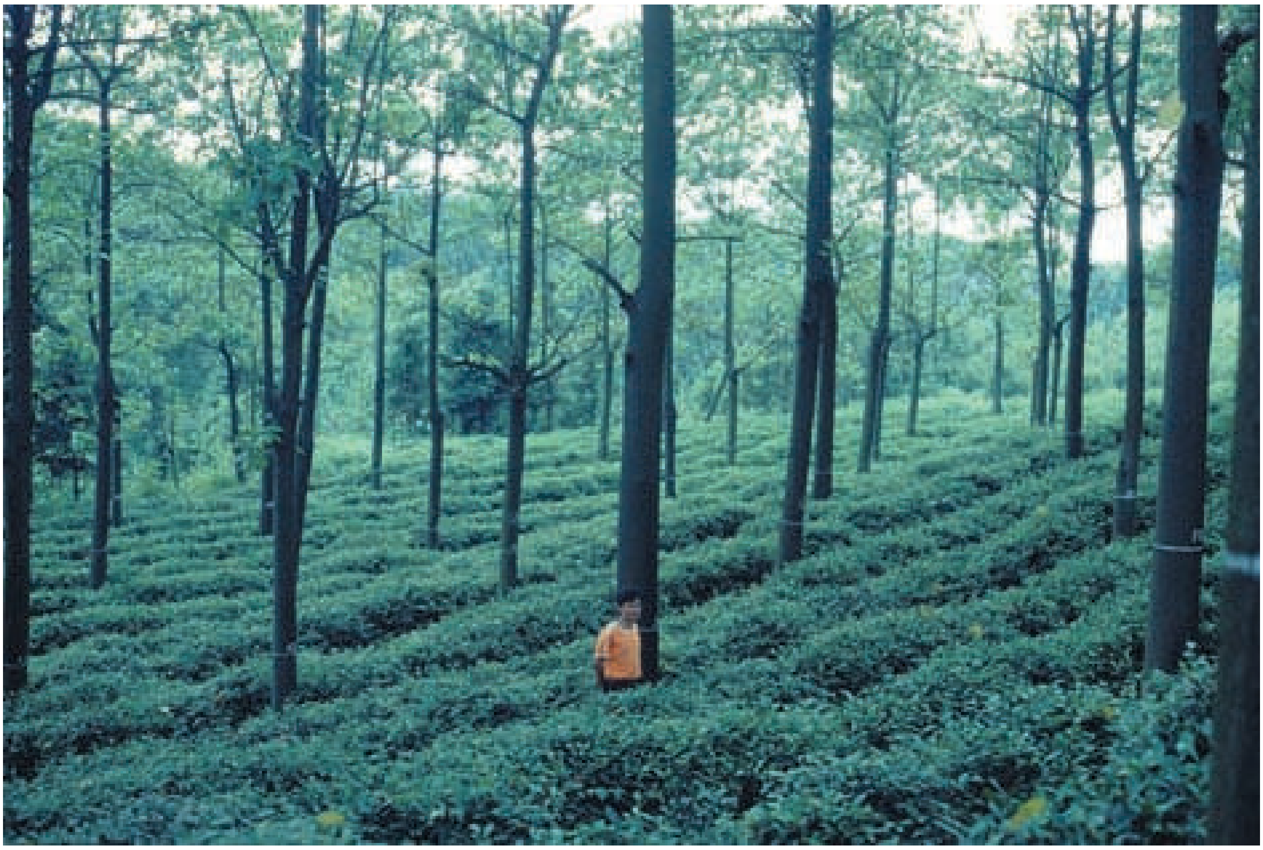


Figure 14: 11-year-old *Paulownia* and tea

There were also 18 ha of tree breeding plantations, gene-banks, and clone testing - including some clones from plus trees. A *P. fortunei* clone C001 is performing very well. Already 50 000 plants have been produced from this for distribution to local farmers. Selection is continuing here and they are trying to develop four or five superior clones. A staff of 140 carry out the forest and research work. Because the forest is close to the city it is used to show city people how important forests are for biological, ecological, sociological, and economic reasons. The total area of the forest is 470 ha of which 300 ha are in forest and 170 ha in other tree crops (e.g., orchards).

Figure 15: *Paulownia* and tea on a steep hillside

The soil here is a clay loam with clay content about 50% and a pH of 5.5. In some parts the soil has more silt and goes to silty clay. The *Paulownia*/edible bamboo is a good income earner, with an annual yield estimated at 15,000 yuan (NZ$5000) per annum.

From a distance we saw a 5 ha clonal trial of 4-year-old *Paulownia* on a poor west facing slope. The soil was thin with bed-rock underneath which caused the growth to be very patchy. It looked as if it could do with releasing but they say they have a problem getting enough labour. Chemical methods are considered too expensive to use. As regrowth here is very fast about three manual releasings a year would be needed.

In a 1980 *P. fortunei* clonal plantation we saw the superior clone C001. It really stood out amongst the rest. Trunk extension is not done on *P. fortunei* because it develops good form naturally. Trunk extension is only done on *P. elongata* and occasionally *P. tomentosa*.

By New Zealand standards silvicultural work seems almost non-existent. *Paulownia* often looked quite rough because of lack of pruning and Chinese fir does not seem to be pruned at all.

We inspected an 8-year-old clonal trial with several species, contained some exceptional *P. fortunei*. Clones C035, C039 and C046 seem best; these had a scattered (multinodal), light branching habit. The rainfall here is 1300 - 1500mm and the altitude ca. 50 - 100 m.

The average labourer's wage is about 2,000 (NZ$700) yuan per annum. Training and holding people on a station like this is difficult (proximity of city), and seems to be a problem in a lot of places. Technical staff move around quite a lot and continuity with experimental work becomes difficult because of this. On the Tongling Forest Farm, despite having 140 staff, there are apparently not enough people to do all of the work. The forest is trying to become self sufficient by growing crops like edible bamboo and tea.

Another southern agroforestry research station we visited was Linlongshan Forest Farm located near Hangzhou. It was established in 1978 and most of the planting was done by 1983. Total area is over 1 500 ha, including 100 ha of reserves and 30 ha of orchard crops and 1 200 hectares of forest. The reserves include representatives of many local tree and shrub species which are now relatively rare in the area. (e.g., *Quercus*, *Acer*). There are 105 staff at the forest farm with annual production in 1988 worth 3.65 million yuan ($NZ1.2 million). This is from all sources: forest, orchard, vegetables, manufacturing (chopsticks and light electrical cable). Money from the industries is important as this supports forestry. The concept of self sufficiency showed up strongly in several places we visited and any surplus money goes to the several villages in the forest or associated with it.

Paulownia work started at Linlongshan a few years ago and several tree species were being trialled in different agroforestry combinations.

- *Paulownia*/tea (*Paulownia* 8 x 10 m; Tea 2 x 0.3 m).
  (In a trial inspected the *Paulownia* was aged 2 on a 3-year root and the tea aged 8).
- *Paulownia*/edible bamboo
- Chestnut/tea
- Wax tree/tea
- Magnolia/kiwi fruit
- Chinese fir/tea(The Chinese fir is wide spaced.)

CASE STUDY

In the Shangqiu Prefecture we visited an integrated operation run by Mr Sung. He rented 32 ha of land that was originally waste, plus a brickworks, from the local village. Before this he was Chairman of another small village. He seems very skilled in adopting and developing the new systems proposed by CAF. His operation, which began in May 1986, initially met with many difficulties but he overcame them. He is supported by the local county government and has an award from them.

Figure 16: Example of multiple use on Sung property: pond, *Paulownia*, *Salix,* and fruit trees

The project contains the following activities:-

- 11 ha of fish ponds
- 9 ha of orchards, mostly apples, with first production this year.
- 1100 *P. elongata* planted around the fish ponds (now 5 years old, ca 10 m. tall and 20-29 cm dbh)
- ca. 1100 *Salix* planted between these (coppiced for basketry)
- 100 pigs
- 6500 ducks
- 24 head of beef cattle
- 20 million bricks produced annually. Earth dug in construction of fish ponds is used for bricks.

Income from the project has been:

1988	200, 000 yuan (3 yuan = NZ$1.00)
1989	260, 000
1990	1, 000, 000
1991 (projected)	2, 000, 000

The fish are fed on pellets containing 20% ground *Paulownia* leaf with other constituents being chaff and waste grain. The percentage of *Paulownia* leaf cannot be increased because at higher proportions the pellets will not hold together.

This is an example of a fully integrated "ecological system”. Or it could be called large-scale permaculture.

Experimental work on feeding fish, pigs, and chickens with *Paulownia* is mainly done elsewhere. The Chinese have tried making feeds with various percentages of *Paulownia* leaf up to 20%, the higher level giving best results. It is suspected increasing the Paulownia component above 20% would give even better results, but 20% has not yet been exceeded because of the problem of pellet disintegration.

Another site owned by Mr Sung is 20 ha in area and here two projects were under way - agroforestry and tree breeding.

In agroforestry there were several combinations, each about 3 ha:-

- *Paulownia*/apples/crops
- *Paulownia*/crops
- *Paulownia*/*Salix*/crops)

There was also a small Forest Net area of about 2.5 ha. All of the trials were established in the spring of 1991 (March). The crops being grown are winter wheat followed by cotton.

The tree-breeding project contained 21 clones with six replications of three trees each, spaced at 5 x 20 m. It was also planted in spring and cropped as above.

A ditch had been dug around this block (with soil going to the brickworks) and it will be used for irrigation and ducks. It is connected to the Yellow River irrigation system but has underground supplies via wells as a supplement.

There is also a 1.5-ha *Paulownia* nursery on the property which was established in March 1991 to supply the surrounding district. Rows of seedlings have been raised 1 m above the surrounding area to increase soil warmth and get a faster strike. Trees were up to 1 m tall and very even.

Paulownia utilisation, prices and markets

A visit was made to the Paulownia Timber Multiple Processing Factory of Shangqiu in Henan Province. The plant was still under construction, work having begun on 5 August 1990 and was due for completion in late 1991. It will process only *Paulownia* and will be the biggest *Paulownia* processing plant in the world. It is a Government sponsored project located here because Shangqiu is acknowledged to be the "home town" of *Paulownia*.

The plant is located on the 17-ha site and will engage in the following processes:-

- sawmill
- plywood
- finger-jointing
- kiln and air drying
- veneer mill (sliced for facing particleboard and rotary for plywood)
- glue manufacture
- particleboard
- furniture manufacture

Figure17: Loading second-grade *Paulownia* logs for processing

The first timber production was to start the day after our visit, with the plant opening (sawmill only) taking place on the 70th anniversary of the founding of the Chinese Communist Party. At this stage the sawmill, one kiln, and some small machinery in the finger-jointing department were the only operational sections and they were on test runs. The sawmill consists of a band breakdown and three band recut saws. The saws are quite small with a kerf of ca. 2.5 mm. Boards will be kiln dried by hot air or air-dried in a large shed. Air drying of 2 cm boards takes 1 week to 30% moisture content.

Annual target figures for some products are:-

• Particleboard	30 000 m^3 (1.5 million m^2)
• Plywood	10 000 m^3
• Veneer	2 000 000 m^2
• Glue	4.5 tonnes

The particleboard plant is designed to utilise quite small branches and is steam (coal) and electrically operated. Mill equipment came mostly from Finland. Construction cost was 1 billion yuan, and operational staff will total 1500.

This factory is expected to play a major role in processing the increasing volumes of *Paulownia* being grown in the Prefecture. Its presence will also encourage further planting. One aspect that was not explained to us was how the flow of logs to the mill will be organised. The impression given was that not a great deal of attention has been paid to this aspect. As the mill will be buying from a huge number of small growers it would seem essential that this aspect be given urgent attention.

The initial prices being offered for logs should encourage further planting and better silvicultural practice.

• 1st class	NZ$870/$m^3$	peeler grade
• 2nd class	NZ$520-600/$m^3$	peeler/sawlog
• 3rd class	NZ$170/$m^3$	particleboard

Apparently these are farm gate prices with the greater volumes being in the third grade.

The minimum length for peeler logs is to be 2.5 m, with a s.e.d. of 28 cm.

Markets for the plant are expected to be in S.E. Asia, Japan, and China.

A nearby furniture factory was also visited. This is a medium-sized operation employing 150 workers and using about 3 000 m^3 of *Paulownia* each year. Most items made are exported to Japan. The remainder are either sold locally or exported to 19 different countries, mainly in Europe. They have been exporting for 6 years and see no problems with future markets 10 or more years ahead. Their sales are increasing as more people become aware of *Paulownia* and its qualities as a furniture timber. Currently demand exceeds supply and, as standards of living in China continue to rise, this trend is expected to continue.

About 60 kinds of product are manufactured including several different types of chests of drawers from small jewel chests to large tallboy types, several types of storage box, Chinese scroll painting, and jewel boxes. The larger items of furniture often have rattan glued to the tops and drawer fronts. Apparently this is quite popular in Japan. Most products seem to be solid wood and not ply or veneer.

The scroll boxes sold for 30 yuan (NZ$10) and the small drawer sets (50-60 cm square and 20 cm deep) for 85 yuan (NZ$28).

The age of the logs sawn is 8 - 10 years. The wood appears to be of good quality with no movement off the saw or subsequent twisting or collapse. The logs being cut during our visit (minimum size 24 cm s.e.d.) were felled last winter (i.e., 6 months ago) and the timber was then air dried for 3 months. The mill is a moderately large band mill travelling carriage and a modern operating system.

We saw many small band-mills in villages as we travelled through China. All appear to be the same type and many were more or less derelict. They have rails beside and look to be manually fed by a moving bench. Occasionally one was seen in good operating condition but never working. It would appear they are used intermittently - according to supply and demand.

We were informed that the average returns per cubic metre sawn are 200 yuan for poplar and 600 yuan for *Paulownia*. Poplar is used for paper, matches, and farm timber. Poplar and *Paulownia* have similar pulping quality but *Paulownia* is seldom used because it is too valuable and has lower fibre content than poplar. The prices paid for *Paulownia* timber are lower in the South than in the North. This is mainly because it is not a traditional timber in the South and because there is a much wider range of timber species available. Until recently *Paulownia* logs brought an average price of 600 yuan/m^3 (NZ$200) to the Chinese grower although for better quality material the Japanese would pay US$500 (NZ$870).

Lessons from China

Paulownia is an integral part of agroforestry land use in the central plains of China. Generally the land is flat with deep alluvial soils mainly used for cropping. *Paulownia* as shelterbelts, part of the Forest Net or in road or village side planting is generally grown with other crops. Rotation length is usually under 10 years, so older trees are rare. Silviculture appears rather haphazard, but the excellent growth rate combined with extension pruning produces trees of good form.

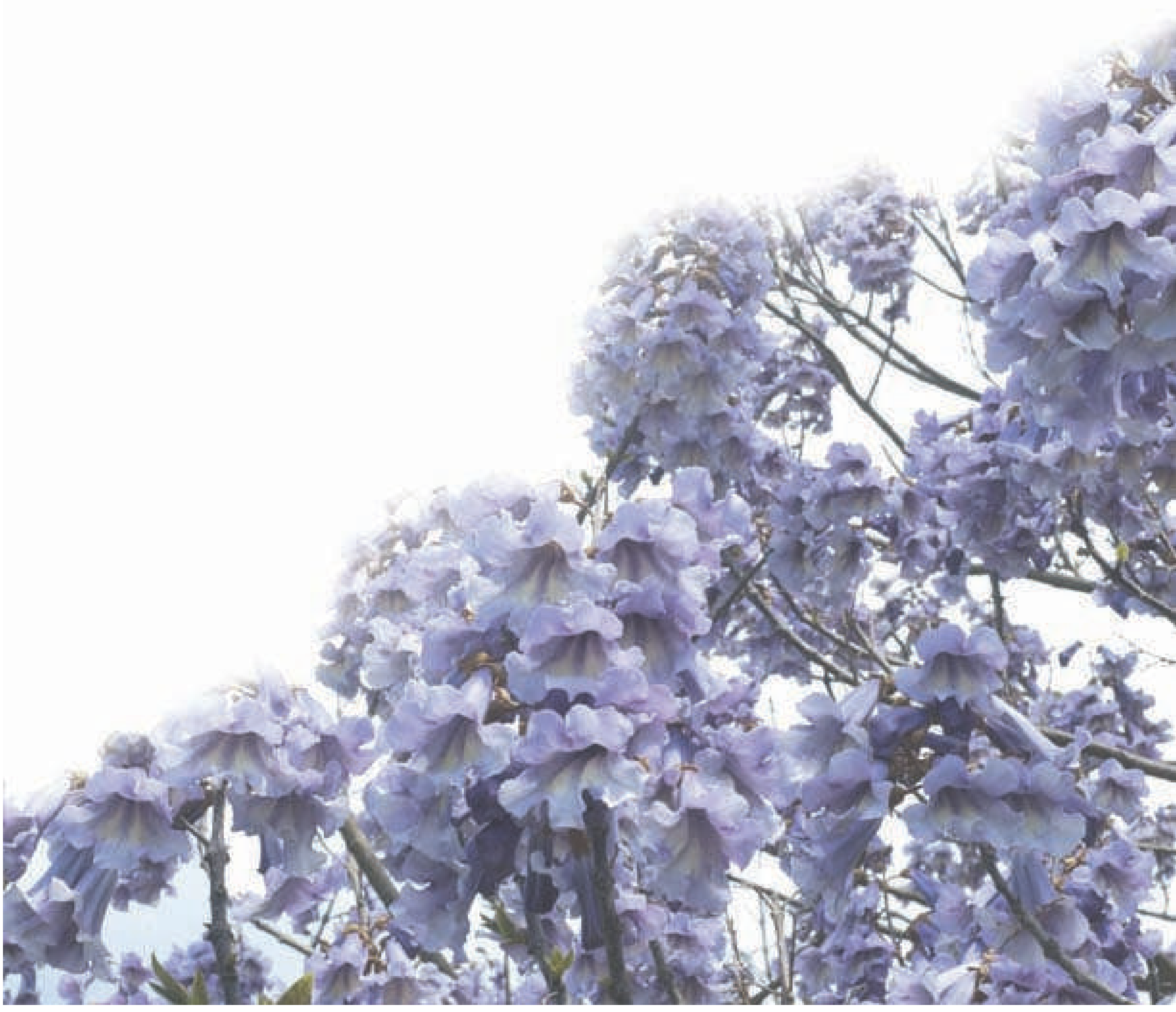
The Chinese consider *Paulownia* the main over-storey tree for intercropping in the plains area and this is a concept that New Zealand could consider in its planting of *Paulownia*. While New Zealand can learn valuable lessons from the nursery and management experiences of the Chinese, the biggest opportunity is how we could incorporate *Paulownia* into our intensive cropping systems. As our crops are often grown in areas combining good soils and mild climate, excellent *Paulownia* growth should be possible as a complement to other crop/horticultural systems such as market gardening.

Key Points

- *Paulownia* is a key part of tree planting in east central China, especially for shelter or agroforestry, usually planted with other plant crops.
- *Paulownia* is an integral part of the Forest Net system in the plains area.
- Nursery production with *Paulownia* is well understood and applied successfully.
- Timber production from shelterbelts or agroforestry is based on log exports to Japan and domestic utilisation.
- Most *Paulownia* grown in China is harvested before age 10.

Additional reading:

Zhu *et al.* (1986)



CHAPTER 3 - RECOGNITION

General description of *Paulownia*

Habit:

Deciduous trees up to 27 m tall. Crowns spreading, open, and rounded to pyramidal.

Bark:

Light grey and smooth or slightly fissured on older trees; soft and easily damaged, especially on trees less than 7 years old.

Leaves:

Opposite, simple, stalked and pubescent. Juvenile leaves ovate, up to 80 cm wide, margins usually coarsely serrate, petioles long. Adult leaves up to 32 cm wide, cordate, margins entire or occasionally three to five lobed.

Flowers:

In terminal branched clusters up to 40 cm long. The calyx is five lobed. Individual flowers 5-11 cm long, petals united into a tube with the upper part divided into five unequal white or lavender lobes, throat often yellow with purple spots. There are four stamens.

Fruit:

A woody capsule 3-10 cm long, beaked, two-valved.

Seed:

Butterfly-shaped, 2-7 mm long, membranous-winged and grooved.

Distinctions from other genera:

Paulownia specimens are most likely to be confused with *Catalpa* in the family Bignoniaceae. *Catalpa* trees are easily distinguished by the much longer seed pods which are usually more than 15 cm long and can be up to 1 m. *Paulownia* has branchlets with a hollow pith, while those of *Catalpa* are solid and whitish. The leaves are similar but the leaf hairs of *Catalpa* are not stellate. In the *Catalpa* flower the calyx is two-lobed, the corolla is bell-shaped and whitish with yellow and dark purplish markings in the throat, and there are five stamens but only two are functional.

Characteristics used to identify *Paulownia* species

Paulownia identification is often difficult, even for the experienced observer, especially since there are a large number of cultivars and hybrids produced during the thousands of years of cultivation. Of the six species, only *P. elongata*, *P. fortunei*, and *P. tomentosa* and some their hybrids are relatively common in New Zealand.

Paulownia kawakamii and *P. fortunei* are the only two species which are relatively easy to recognise. Unless flowering, the other four species are often difficult to separate on the basis of simple features readily visible without magnification. Hybrids can only be identified by the presence of features intermediate between the parent species.

Leaves:

The size and shape of *Paulownia* leaves vary considerably within a species and even on a single tree. Young plants, coppice growth and vigorous shoots have particularly large, lobed leaves (Fig. 18). Mature leaves of some species may differ in the size, shape, shininess of the upper surface or in the shape of the minute hairs on the under-surface (Fig.19, 20). In the absence of flowers and fruit, examination of leaf hairs can be useful in separating *P. tomentosa* and *P. fargesii* from the other four species but magnification greater than 10x is needed in order to see the hairs clearly.

The hairs found on the under-surfaces of "young" leaves are usually sparse and unbranched. They are often glandular, with bulbous tips (Fig. 19) making the leaf surface sticky to the touch.

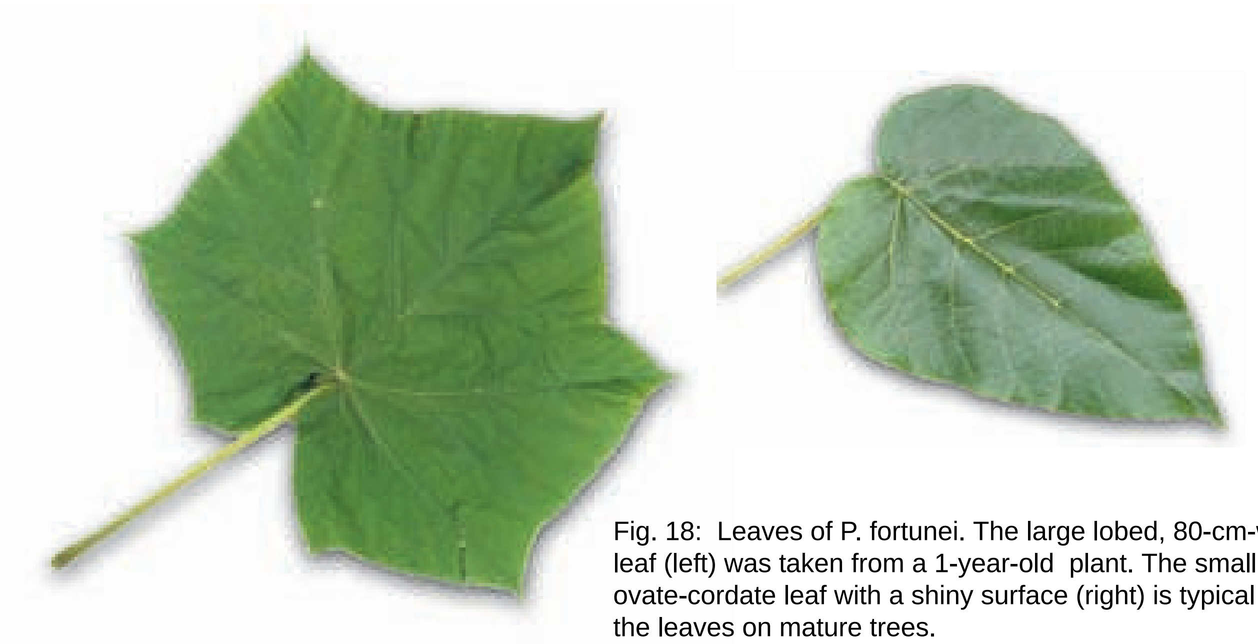


Fig. 18: Leaves of P. fortunei. The large lobed, 80-cm-wide leaf (left) was taken from a 1-year-old plant. The smaller ovate-cordate leaf with a shiny surface (right) is typical of the leaves on mature trees.

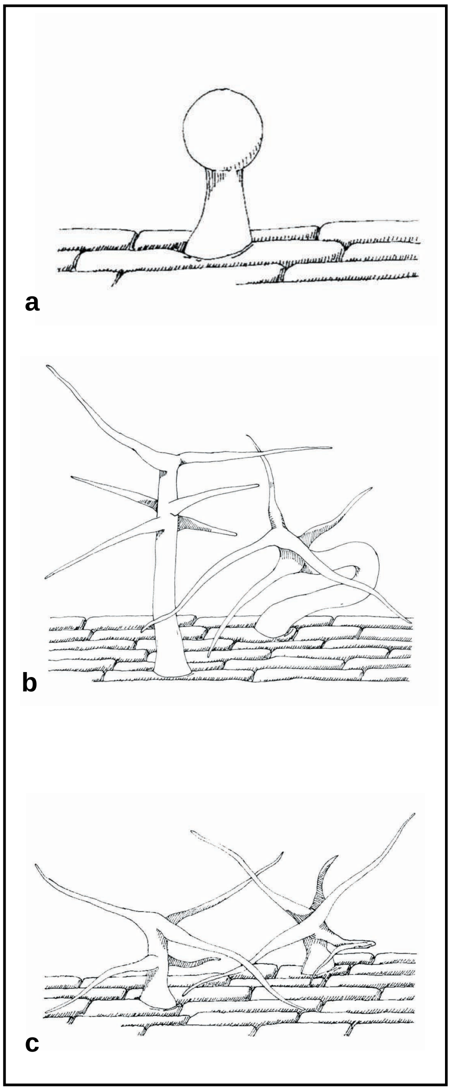


Fig.19: a: glandular hair; b: stalked stellate hairs; c: sessile stellate hairs.

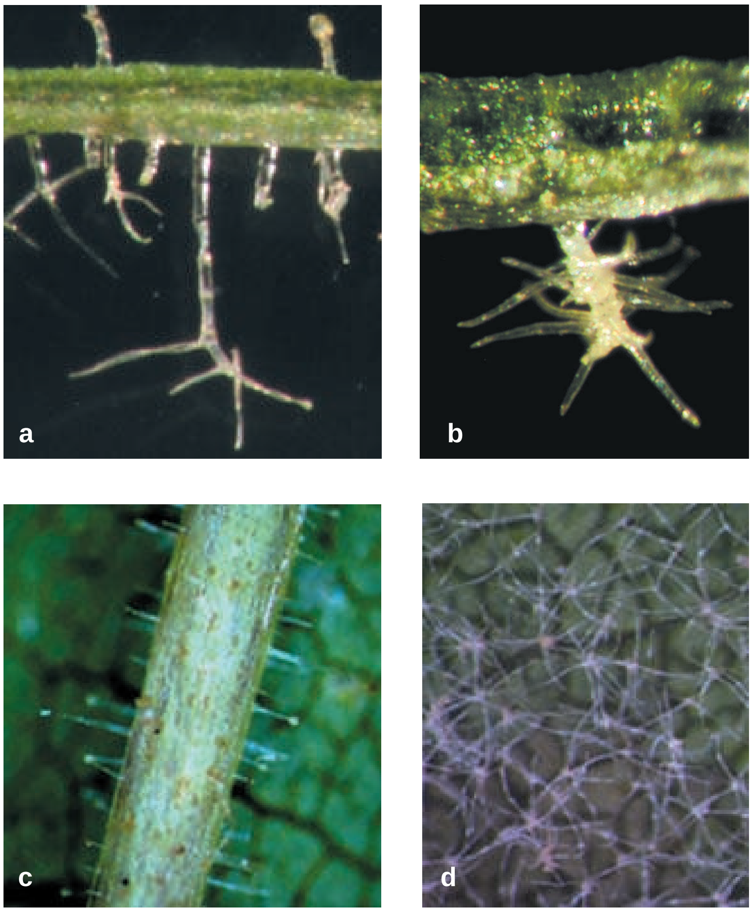


Fig. 20: (a) Cross-section of a leaf of *P. tomentosa* with a stalked stellate hair on the lower leaf surface and a glandular hair on the far right of the upper surface. (b) Cross-section of a leaf of *P. elongata* with a sessile stellate hair on the lower leaf surface. (c) Hairs on the undersides of young leaves are usually sparse and unbranched. Some may be glandular, with bulbous tips, as on this leaf vein. (d) Hairs on mature leaves of all species except *P. kawakamii*, are dense and branched (magnification ca × 50).

Flowers, fruit, and seed

Flowers and seed capsules are useful for identification but they are found only on mature trees and are present only for a limited season. The species do differ in flowering times and the flowering patterns were recorded for four species at Hunua, near Auckland. *Paulownia fortunei* was the first species to flower, in August; *P. elongata* flowered from early September; *P. tomentosa* flowered from late September to November; and *P. fargesii* from early October.

Inflorescences (flowerheads, Fig. 21) can vary in size and structure, even within a species and on the same tree. In the descriptions given here, the number of flowers in a cluster (cyme), length of pedicels, and length of the peduncles apply only to flowers in the mid-section of the inflorescence. The corolla length includes the calyx (Fig. 22) and the corolla width is measured across the fully open flower. The size and structure of the inflorescence can be useful for identification although there is a tendency for the inflorescences nearer the very top of the tree to be larger. The inflorescence structure is easier to see just prior to flowering and leaf burst. At this stage the colour of the closed flower buds can also be distinctive.

The mature fruit is a dry, brown, two-valved capsule which splits open to shed large numbers of small, winged seeds. Seed measurements include all of the wing structure.

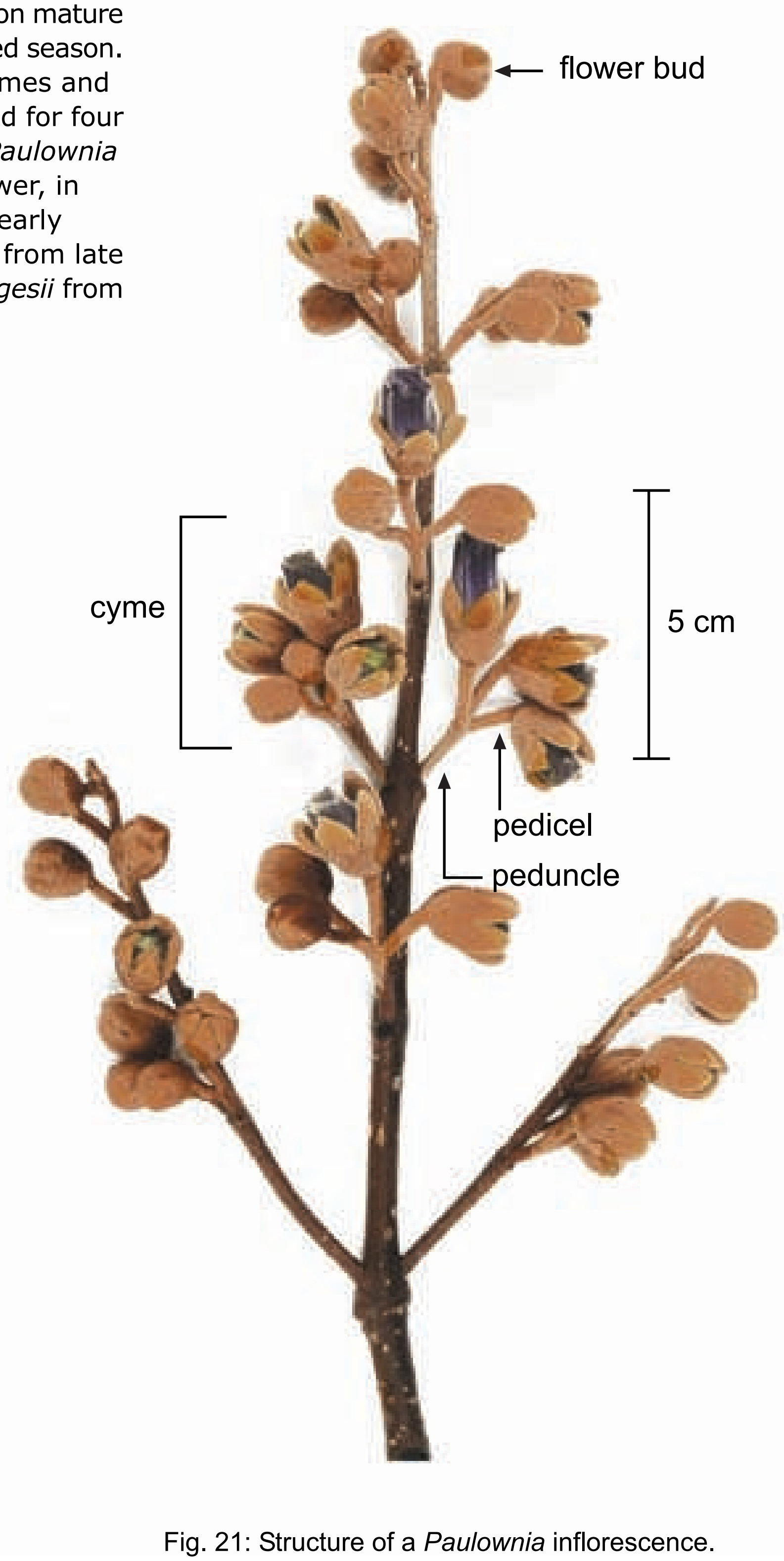


Fig. 21: Structure of a *Paulownia* inflorescence. (Note the flower buds, peduncles, and pedicels)

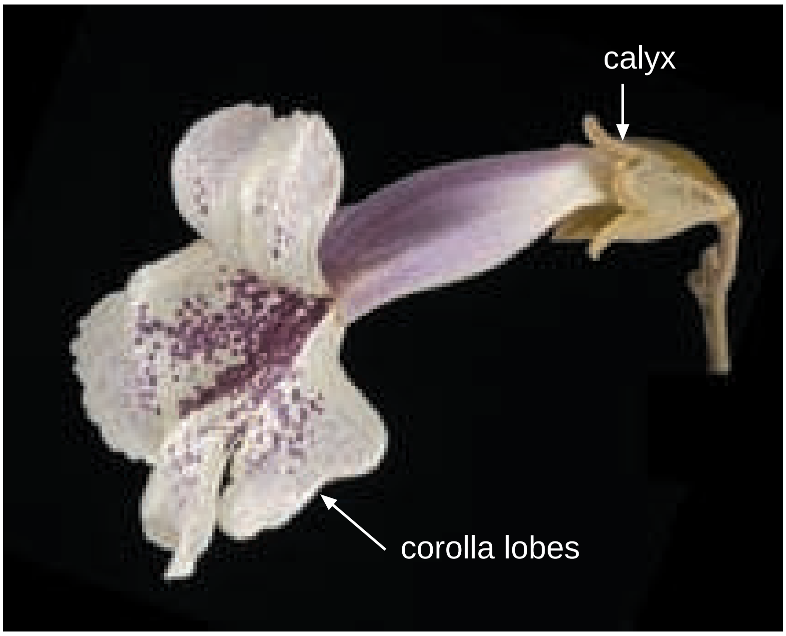


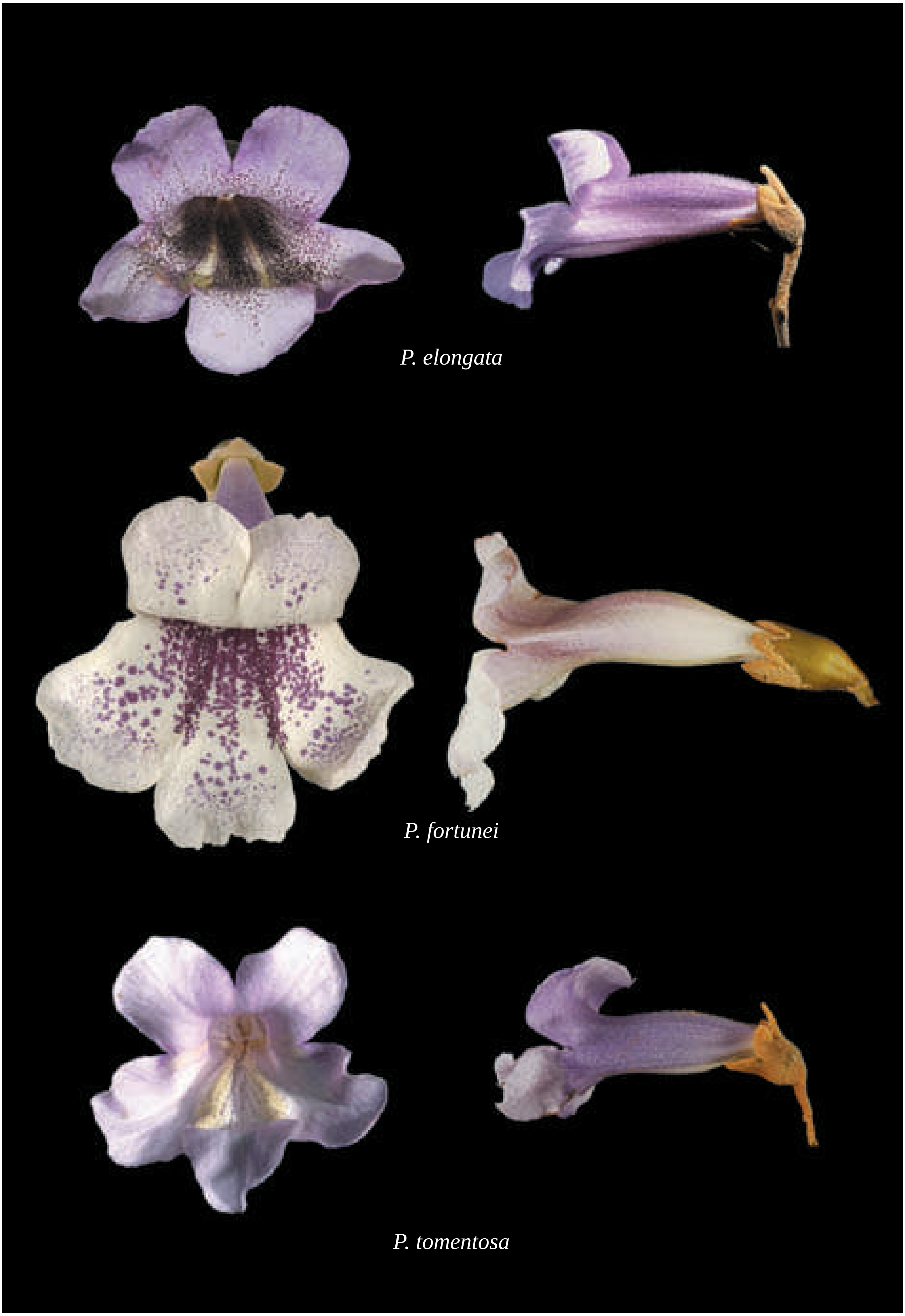
Fig. 22: Paulownia flower showing calyx and corolla lobes.

Fig. 23: Flowers of four *Paulownia* species and a hybrid (from left, top row: *P. fargesii, P. tomentosa*, bottom row: *P. fortunei, P. elongata* × *P. tomentosa, P. elongata).*

Table 1: Recognition of *Paulownia* species

	P. catalpifolia	***P. elongata***	***P. fargesii***
Distinguishing features	Leaves narrow, ca. 2 times as long as wide. Hairs on underside of mature leaves sessile and branched. Inflorescence often branched, clusters usually with long peduncles. Flowers spotted, <8 cm long. Capsule ellipsoid. Distinguished from *P. elongata* by the narrower leaves, longer inflorescences, smaller flowers and ellipsoid capsules. Not known in New Zealand.	Leaf hairs sessile, branched. Inflorescence short. Flowers variable in colour but often purplish, spotted, >8 cm long. Distinguished from *P. catalpifolia* by the wider leaves, shorter dense inflorescences, larger flowers, and ovoid seed capsules. Commonly cultivated.	Inflorescence large, up to 1 m, with a few long branches near the base and upper clusters sessile. The flowers are very similar to *P. tomentosa* in size but paler in colour. Uncommon in cultivation.
Mature leaves (Descriptions are for mature, fully expanded leaves from plants that are at least 3 years old. It is important to select mature leaves for identification purposes.)	Leaf blade ovate-cordate, tip acuminate. Hairs on underside branched and +/-sessile.	Leaf blade ovate-cordate, 16-38 cm long, 10-22 cm wide, gradually attenuate, tip acute. Hairs sessile, branched.	Leaf blade ovate to ovate-cordate, sometimes lobed, 20-22 cm long, ca 20 cm wide, tip acuminate. Hairs stalked, shortly branched.
Inflorescence	Inflorescence <35 cm long. Peduncles nearly as long as pedicels.	Inflorescence 25-30 cm long, sometimes shortly branched. Peduncles 8-20 mm long, pedicels 10-30 mm long.	Inflorescence up to 100 cm long, with a few long branches especially near the base. Upper flower clusters usually sessile or subsessile with peduncles 1-12 mm long, pedicels 12-15 mm long.
Flowers (Corolla length is measured to base of calyx. Corolla width is measured across lobes).	Calyx 15-20 mm long, calyx lobes 6-8 mm long. Corolla 7-8 cm long, 3-5 cm wide, light purple, tube only slightly flared, ridged inside, white to pale yellowish, usually with dense, small purple spots.	Calyx 15-25 mm long, calyx lobes (5)8-11 mm long. Calyx densely hairy and pale cream in bud. Corolla (7)8-10 cm long, 4-7 cm wide, flared from the base, purple to pinkish white, tube strongly ridged, yellowish and purple spotted in the throat.	Calyx 13-20 mm long, calyx lobes 6-9 mm long. Calyx densely hairy and pale orange-brown when in bud. Corolla 5-9 cm long, 4-6 cm wide, white to pale purple, tube slightly flared, yellowish ridges inside, sometimes with small purple spots or striations.
Fruit (seed capsules) and seeds (Atypical capsules should be avoided)	Capsules ellipsoid, 4.5-5.5 cm long.	Capsules ovoid, 3.5-5 cm. long. Seeds 4-5 mm long, 2.5 mm wide.	Capsules ellipsoid to ovoid-ellipsoid or almost globular, 3-4.5 cm long. Seeds 4-(6) mm long, 2.7 mm wide.

P. fortunei	*P. kawakamii*	*P. tomentosa*
Leaves shiny above, flowers and capsules large. Inflorescence short, unbranched, dense. Flowers often >10 cm long, calyx shallowly lobed and usually partially glabrous, corolla tube widely flared (Fig. 23); capsules >5.5 cm long. Early flowering, from early August. Commonly cultivated.	Mature leaves sticky, often lobed with unbranched glandular hairs on the lower surface. Flower cluster usually sessile. Flowers small, <5 cm long. Calyx deeply lobed, lobes reflexed in fruit. Rarely cultivated.	Leaf hairs stalked and branched. Calyx small and deeply lobed. Inflorescence relatively open and less dense than *P. elongata* and *P. fortunei*. Late-flowering, usually starting in late September. Commonly cultivated.
Leaf blade shiny above, ovate-cordate, 14-32 cm long, 7-20 cm wide, tip acuminate. Hairs on underside sessile, branched.	Leaf blade cordate, 20-35 cm long, 15-32 cm wide, margins 3-5 lobed or entire, tip acute to obtuse. Hairs on underside unbranched, glandular. Leaves sticky to touch.	Leaf blade broad, cordate, occasionally lobed, 12-30(40) cm long, up to 30 cm wide, tip acute. Hairs on underside very fine, stalked, long branched.
Inflorescence unbranched, ca. 25 cm long. Peduncles 8-18 mm long, pedicels 15-22 mm long.	Inflorescence up to 100 cm long, upper flower clusters often sessile or peduncles <12 mm.	Inflorescence up to 50 cm long, branched. Central flower clusters with peduncles 10-20 mm long, pedicels 10-20 mm long.
Calyx (18)20-30 mm long, lobes 6-9 mm long, and pale cream when in bud. Calyx hairs easily rubbed off. Corolla 8-14 cm long, 6-8 cm wide, whitish, tube widely flared, throat usually purple spotted or blotched and not or only weakly ridged at throat, lobes often serrated.	Calyx 10-11 mm long, deeply lobed. Calyx densely hairy. Corolla 3-5 cm long, 3-4 cm wide, pale violet to blue-purple.	Calyx 10-18 mm long, lobes 4-8 mm. Calyx densely hairy and light orange especially when in bud. Corolla 5-8 cm long, 3-6 cm wide, pale blue-purple, tube ridged, occasionally striped or finely spotted inside, conspicuously hairy outside.
Oblong to oblong-ellipsoid, (5)6-8(10) cm long, 3-4.6 cm wide. Seeds 6-10 mm long, 3.8-5 mm wide.	Ovoid, 2.5-4 cm long. Seeds 3-4 mm long, 2.4 mm wide.	Ovoid, 3-4.5 cm long. Seeds 2.5-4(5) mm long, 3 mm wide.


P. elongata
P. fortunei
P. tomentosa

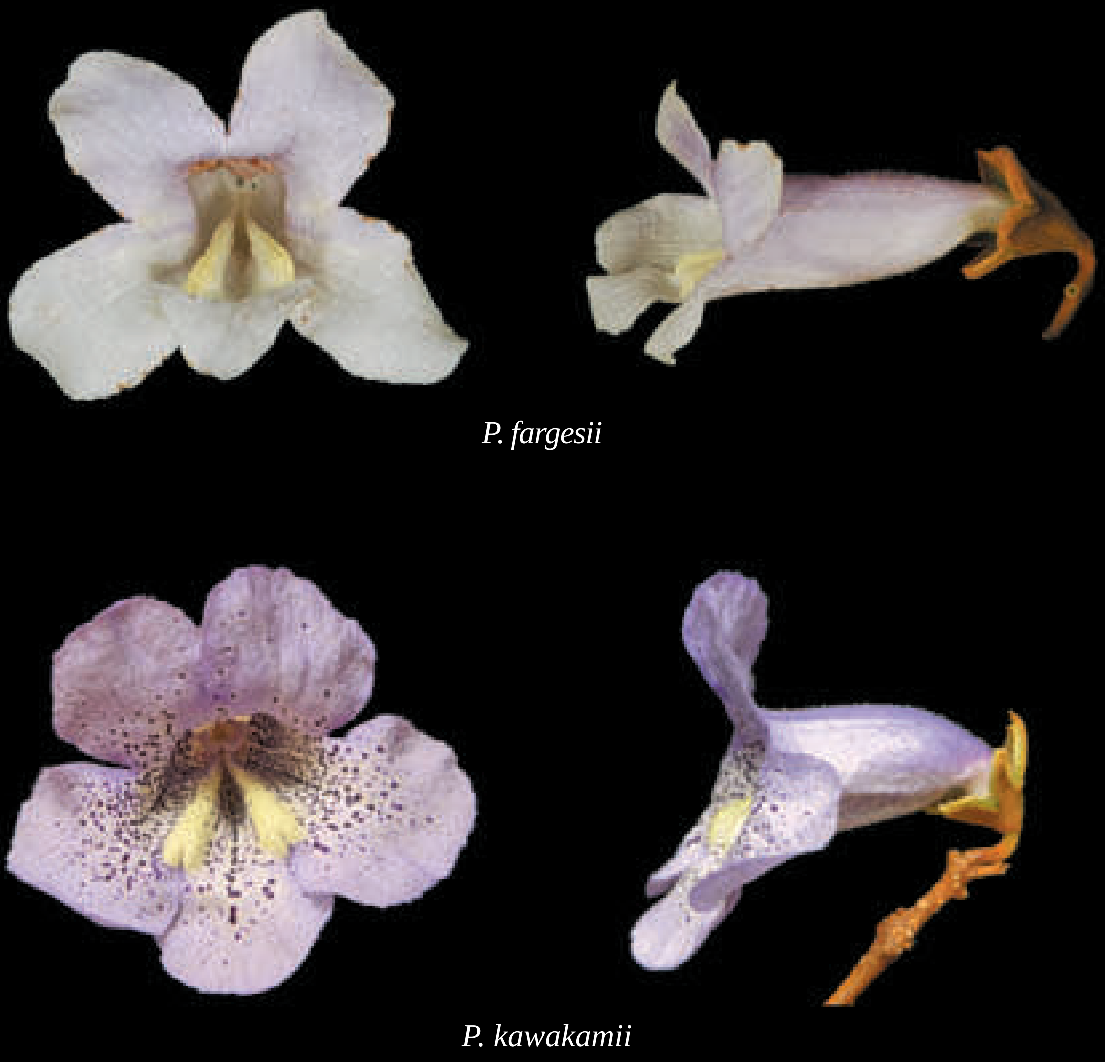


Fig. 24: Side and frontal views of flowers of five species of *Paulownia*.

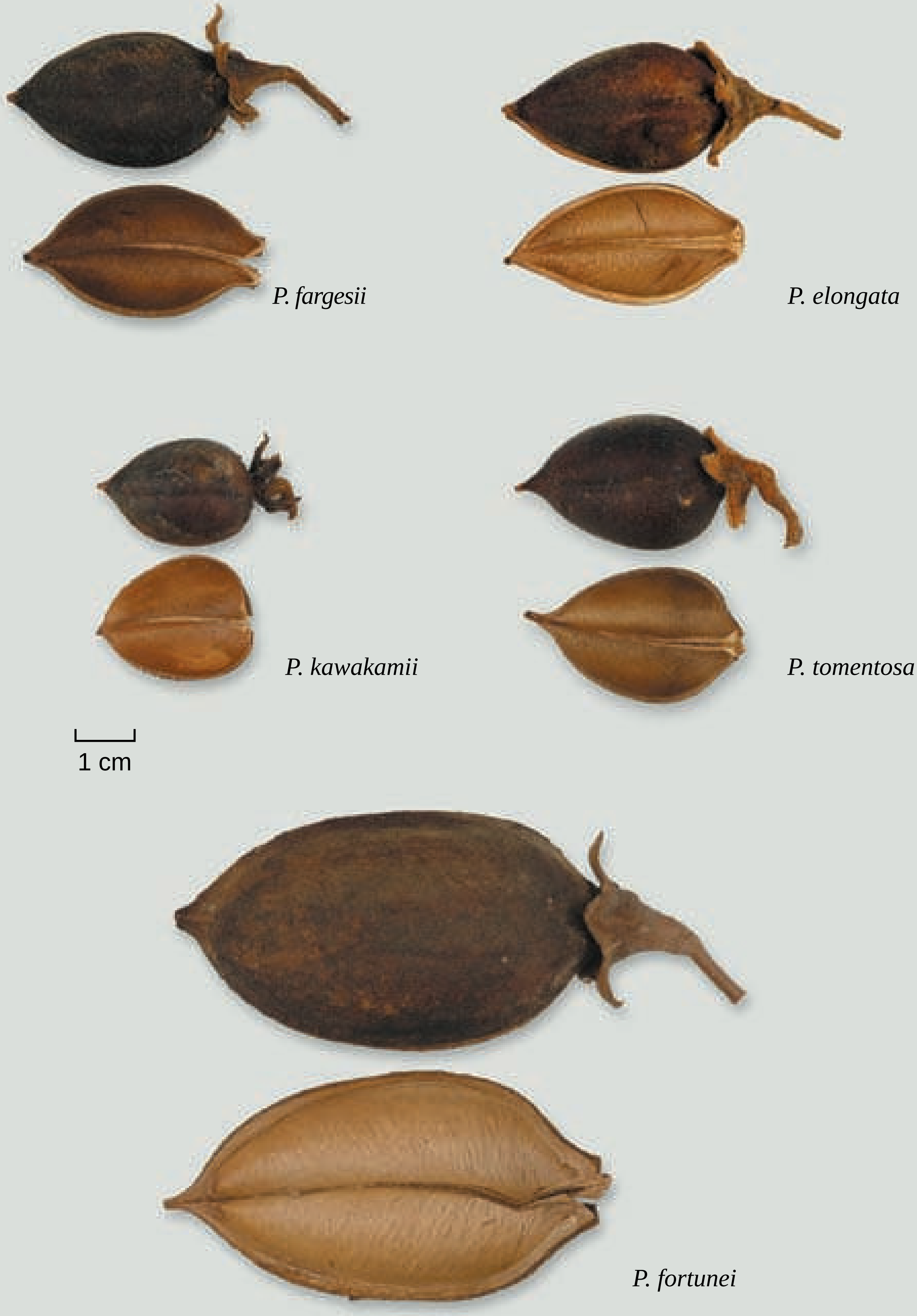


Fig. 25: Seed capsules of five species shown life-sized. Note the thick wall of the *P. fortunei* capsule and the small *P. kawakamii* capsule.

KEY TO *PAULOWNIA* SPECIES

Note: A ×20 lens will be needed for examination of the leaf hairs.

1. Upper leaf surface shiny, flowers 8-12 cm long, calyx >20 mm long, corolla tube not ridged, fruit 5.5-10 cm long .... *P. fortunei*

   Upper leaf surface not shiny, flowers <10 cm long, calyx <25 mm, corolla tube ridged, fruit < 5.5 cm long 2

2. Lower surface of mature leaves with unbranched glandular hairs; leaves sticky to touch; flowers <5 cm long .... *P. kawakamii*

   Lower surface of mature leaves covered with branched (stellate) hairs; leaves not sticky to touch (note immature and early spring leaves may be sticky); flowers >5 cm long ... 3

3. Stellate hairs on lower surface of mature leaves distinctly stalked 4

   Stellate hairs on underside of leaves either sessile or shortly stalked 5

4. Inflorescence cylindrical with a few long branches near the base, upper flower clusters sessile or occasionally very shortly pedunculate .... *P. fargesii*

   Inflorescence pyramidal with short branches, upper flower clusters clearly pedunculate .... *P. tomentosa*

5. Flowers <8 cm long, capsules ellipsoid, leaves ca 2x as long as wide ...... *P. catalpifolia**

   Flowers 8-10 cm long, capsules ovoid, length of leaves <1.5 x width .... *P. elongata*

[* Not known in New Zealand.]

GLOSSARY:

Acuminate: Tapering to a fine point.

Acute: Sharply pointed.

Calyx: The sepals at the base of the flowers, usually green or brown in colour.

Capsule: A dry, dehiscent fruit.

Cordate: Heart-shaped with the notch at the base.

Corolla: The petals.

Ellipsoid: Elliptic (rounded at both ends, widest in the middle) in section or outline.

Globular: Spherical.

Inflorescence: Head or cluster of flowers.

Oblong: Longer than broad, with sides nearly parallel.

Obtuse: Blunt.

Ovate-cordate: Egg and heart-shaped, widest and notched at the base.

Ovoid: Solid body with an ovate outline.

Peduncle: A common axis bearing several flowers.

Pedicel: The stalk of an individual flower.

Pubescent: Very finely hairy.

Sepal: A green, often leaf-like, part of the outer whorl of a flower.

Sessile: Without a stalk.

Subsessile: Having only a very small or rudimentary stalk.

Stellate: Star-shaped.

CHAPTER 4 - GENETIC IMPROVEMENT AND SPECIES COMPARISONS

The first hybrids of *Paulownia* in China were completely fortuitous, resulting from inter-specific crosses through cross-pollination from species that had been under cultivation. If, as stated by Ch'en Chu, only two species existed in 1049, all those described later may be hybrids derived from a proto-*P. tomentosa* and a proto-*P. fortunei*.

Modern genetic improvement of *Paulownia* began in the early 1970s (Xiong 1990). Seed was collected from 831 superior trees throughout China and the superior strains in use today are derived from that collection. The procedure used in the selection process (Zhu *et al.* 1986) is summarised in Fig. 26.

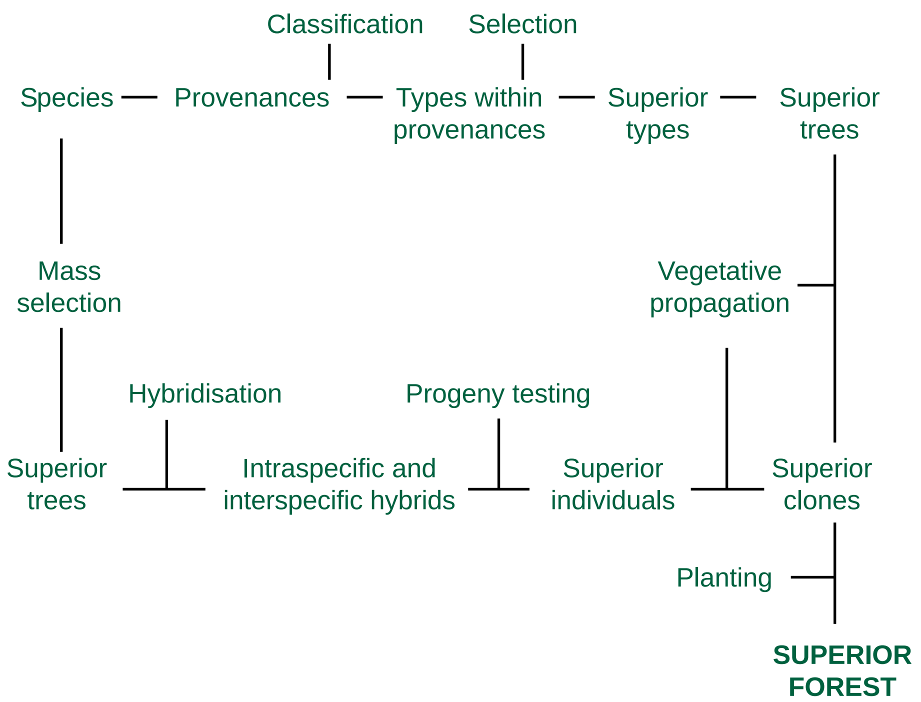


Figure 26: Selection of superior candidates for *Paulownia (from Zhu et al. 1986)*

Trials in New Zealand

From 1989 to 1991 the Paulownia Action Group established a series of trials designed to demonstrate the potential of a range of species and provenances. These included:

- *P. tomentosa* - Chinese, Japanese and New Zealand origins
- *P. fortunei* - four Chinese provenances
- *P. elongata* - two Chinese provenances.

Trials based on the same key seedlots, were established at Glen Murray in 1989, and in Hamilton and Te Kuiti in 1990. In 1991 five more trials were established near Kaikohe, Te Puke, and Rangiora, and in the Wairarapa and Banks Peninsula. These included additional individual seedlots of *P. fargesii* and *P. catalpifolia* collected in China.

Early results demonstrated a considerable amount of variability between seedlots and species. None of the species performed well at all sites.

By 1994 all trials except those at Glen Murray and Te Puke had been abandoned. Failures were attributed to frost damage, drought, poor soils, or damage by farm animals. Only the Te Puke trial showed satisfactory growth. Trees at Glen Murray were coppiced in order to improve their form, but a combination of strong winds and poor soils resulted in slow growth. Trees in the Te Puke trial were finally felled in 2004 and replaced with kiwifruit.

Failure of most of the species trials confirmed the experience of early New Zealand growers when exploring forestry potential. *Paulownia* is clearly site-sensitive and cannot tolerate heavy soils or frost-prone sites. The Te Puke trial showed that good growth can be achieved under favourable conditions.

Figure 27: Te Puke species trial. Trees 13 years old

One of the objectives of the group was to maintain genetic resources. The largest archive was established on the property of Ian Barton at Hunua, this has been sold and is no longer secure. The best archives are on a number of individual farm forestry properties. With the reduction in interest in Paulownia there is no protection of material. Future planting programmes would be best to utilise selections from current plantations, and import from plantation programmes in Australia, and then directly from China.

Key Points

- Early results from species trials showed no clear superior species for New Zealand conditions.
- The majority of trials established by the Paulownia Action Group failed due to siting problems.

Additional reading:

Xiong (1990)
Zhu *et al.* (1986)
Ye Gouyou *et al.* (1995)

Temperature

Paulownia is known to tolerate a wide range of temperatures. In China the northern limit appears to be related to the January -5°C isotherm. In the south, trees grow where the summer maximum exceeds 40°C. When dormant they can withstand temperatures of 2°C (*P. taiwaniana*) and -20°C (*P. tomentosa*).

In New Zealand, diameter growth in 5 to 9-year-old trees at Hunua (40 km south of Auckland) begins in September (Mean Monthly Temperature[MMT] 11°C) and ceases in April (MMT 15°C). In the nursery, seedling height growth commences when MMT is 16°C and ceases at MMT 14°C. During the peak growth season (mid-January to mid-March), growth rates decline whenever the mean weekly temperature falls below 16°C (Figure 28).

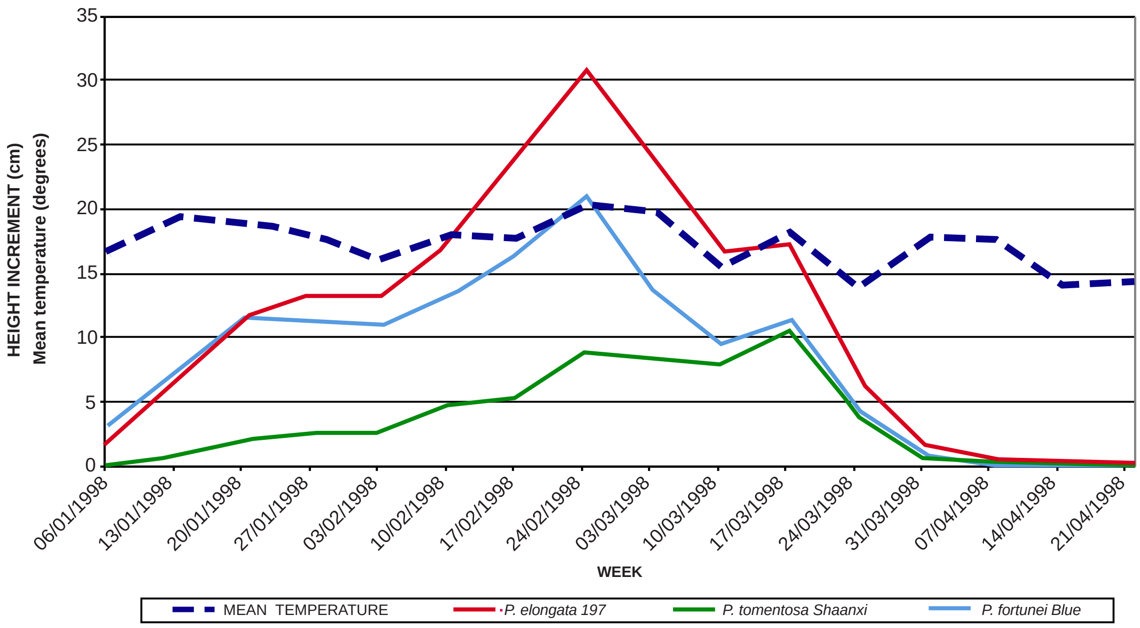


Figure 28: Height increment of *Paulownia* spp. over the 1998 January-April period.

The above data and meteorological information can be used to define areas of New Zealand in which *Paulownia* can be expected to grow well.

Rainfall

Paulownia, in China, grows where annual rainfall is as low as 500 mm if this rain falls during the growing season. It also grows in regions of high rainfall (up to 3000 mm). The main requirement is for water to be plentiful during the period of maximum growth.

In New Zealand, winter is usually the season of maximum rainfall. *Paulownia* can only be expected to grow well in areas where summer rainfall is adequate, or where the land can be irrigated. If soil becomes saturated with water during winter for more than a few days, the trees may struggle to survive.

Information from China suggests that the most drought-tolerant species is *P. tomentosa*, followed (in order of decreasing tolerance) by *P. elongata*, *P. kawakami*, *P. fortunei*, and *P. catalpifolia*. No data exist for *P. fargesii*.

Light

Paulownia is a light-demanding genus. Work with *P. elongata* and *P. taiwaniana* has shown that the light saturation point is 60 000 lux (60% full sun), a very high value compared to that for most other tree species (20 000 - 30 000 lux, 20-30% full sun). The light compensation point (2000 lux, 2% full sun) is very high, (Zhu *et al.* 1986).

Paulownia fortunei and *P. fargesii* exhibit a greater degree of shade tolerance than other species.

Wind

Paulownia seeds are dispersed by wind and have been known to travel for distances up to 1 km from the parent tree. Strong winds can break young plants and saplings (Zhu *et al.* 1986) but do not seem to cause much damage to older trees in China.

In New Zealand, wind damage is more pronounced and wind patterns must be considered during site selection. Breakage of young stems and branches can occur when wind speed exceeds Force 6 (>40 km/hour). Wind affects crown shape in *Paulownia* and may inhibit height growth after the third or fourth year. Any plantation in New Zealand should be sited and managed so that the speed of wind blowing through is no greater than Force 4 (28 km/hour).

Soil

Paulownia will grow on a wide range of soils, but the best development occurs in those that are deep and well drained. A clay component greater than 25% and porosity of less than 50% are not suitable (Hu 1959). *Paulownia fortunei, and P. tomentosa* are more tolerant of clay soils than *P. elongata*. *Paulownia* will not grow where drainage is poor and trees will die if soil which is relatively dry in summer becomes water-logged in winter.

Paulownia does not tolerate soil salinity in excess of 1% (Zhu *et al.* 1986).

In New Zealand, well-drained alluvial soils or volcanic loams appear to support the best growth of *Paulownia*. Where there is a high percentage of clay in the subsoil, as at Hunua near Auckland, growth is rapid during the first few years but then slows down (Figure 29). This is thought to be due to restriction of the root system to upper soil levels where nutrient levels soon become inadequate for continuing high productivity. Deep ripping undertaken at some sites should prove beneficial but no measured results are available.

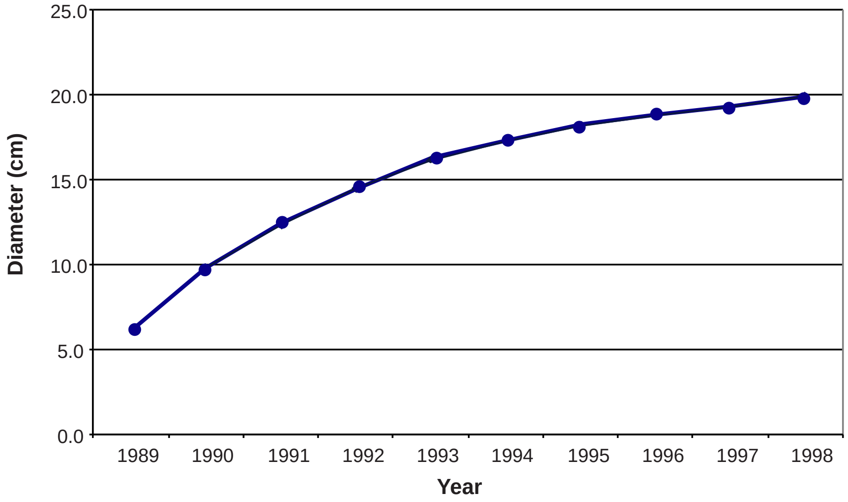


Figure 29: Diameter growth of *Paulownia fortunei* at Hunua, near Auckland.

Good growth can be achieved at soil pH values of 5.0 - 8.9 (Zhu *et al.* 1986).

Paulownia will grow in nutritionally infertile soils if texture and drainage are satisfactory. There is some evidence that application of nitrogen fertiliser will increase the growth rate of young plants.

Choice of *Paulownia* species for New Zealand sites

For over 100 years the only experience of *Paulownia* in New Zealand was derived from a single variety of *P. tomentosa*. Other species have not been in the country long enough for their potential at different sites to be assessed. In spite of this, it is possible to formulate expectations based on data available from China.

Mean summer temperatures in New Zealand (15-19°C) are cooler than those occurring over much of China (24-30°C). *Paulownia* species commonly found in cooler parts of China should therefore be better suited to our conditions. According to Zhu (pers. comm.) these are *P. tomentosa*, *P. catalpifolia* and *P. elongata*. Limited results from trials in New Zealand suggest that some provenances of *P. fortunei* and *P. fargesii* may also be suitable.

At this stage there is no evidence to suggest which particular New Zealand soil types would be most appropriate for *Paulownia* plantations.

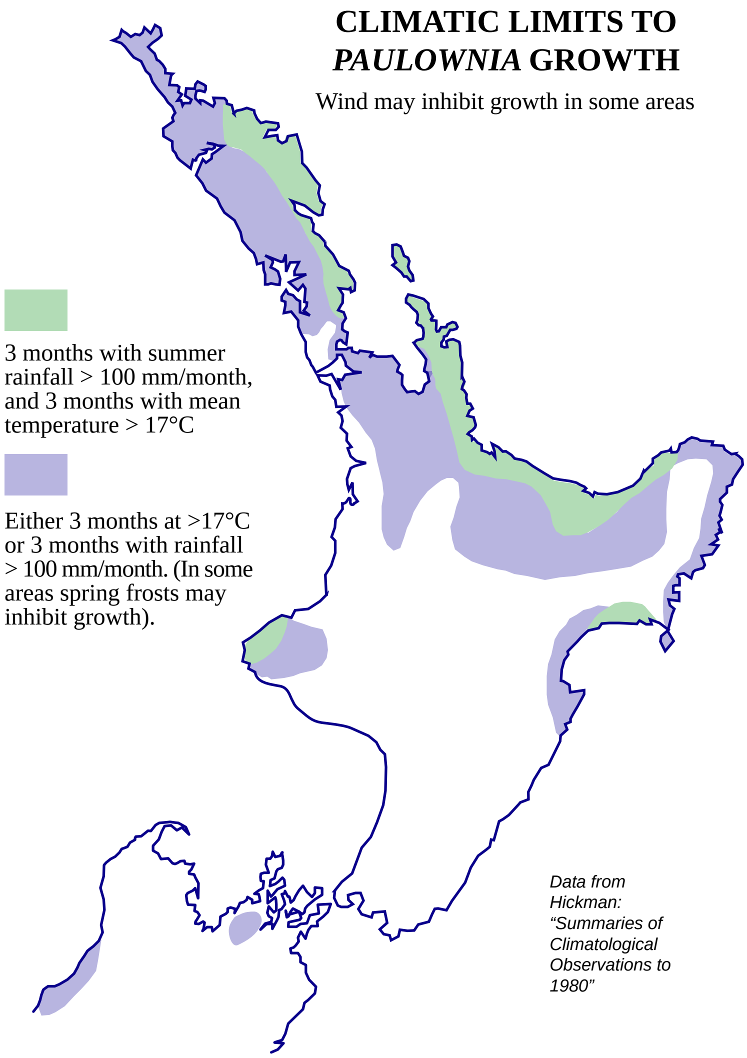


Figure 30: Areas most likely to find requirements for commercial *Paulownia* growth in New Zealand

Potential sites for *Paulownia* in New Zealand

Sites likely to be most suitable for growth of *Paulownia* will have the following characteristics:

- Hot summers (Mean Monthly Temperature higher than 17°C for at least 3 months); mean temperature in October higher than 14°C.
- Mean Monthly Rainfall in summer at least 50 mm and preferably more than 100 mm.
- Soil well-drained with low clay content; water table lower than 1.5 m.
- No frosts between September and April.
- Wind force seldom exceeding 28 km/hour.
- Slopes with northerly aspect exposed to maximum available light.

Sites combining all of these characteristics are not common in New Zealand. Areas in which most of the requirements may occur are indicated in Figure 30.

Figure 31: 12-year-old-*P. elongata* growing at a favourable site near Opotiki, Bay of Plenty

Key Points

- In New Zealand Paulownia requires well-drained fertile soils with high temperatures and consistent summer rainfall.
- Sites with wind exposure and out-of-season frosts should be avoided

Additional reading:

Barton (1993)
Barton (1995a)
Barton (1998)
Ede (1998)
Zhu *et al.* (1986)

CHAPTER 6 - NURSERY PRACTICE AND PROPAGATION TECHNIQUES

Nurserymen generally find that *Paulownia* is easy to propagate by seed and by cuttings. There is little need for budding and grafting. Good general nursery practice is required, fertile soil and adequate weed control being of prime importance for the production of healthy plants. If conditions are not ideal, growth rates may reach only a fraction of their potential.

Mounding-up of nursery beds before planting is important for the following reasons:

- The depth of topsoil is increased and the high demand for soil nutrients is more likely to be satisfied.
- Raising of the beds increases spring soil temperature. In many parts of New Zealand ground temperatures may be too cool for *Paulownia* seedlings or cuttings to thrive.
- Mounding improves soil aeration. *Paulownia* appears to grow best in light, friable soil.
- The risk of waterlogging is reduced. Although *Paulownia* requires adequate moisture, waterlogging can result in serious rotting of the roots.

The raising of nursery beds appears to be common nursery practice in China (Figure 32).

Figure 32: Example of raised bed nursery rows in China

Collection, extraction, and handling of seed

Seed pods form in September-October and although they grow rapidly they do not ripen until the following June, just before leaf-fall. Collection of pods is best done as soon as they begin to turn brown (about May). The collected material is dried on trays kept in a warm dry place. When completely brown, the pods are separated from twigs, petioles, and calyx remnants, and then crushed. Shells are removed by vigorous shaking in a container, followed by coarse sieving. Further sieving through fine mesh in a draft-free room will remove dust.

Seed will remain viable for at least 11 years if stored in an airtight container at 4-5°C. In a recent test, seed samples that had been stored in this way for 6 months to 11 years took 25-28 days to germinate.

Growing from seed

One small *Paulownia* pod holds hundreds of tiny seeds and, because their viability is invariably high, only a few pods are required for production of a large number of seedlings. Collection from as many trees as possible will increase the genetic diversity of the next generation.

Germination and early growth can be improved by stratification of the seed. Stratification mimics temperature and moisture conditions of the natural winter dormancy period. Storage for 4-6 weeks in moist peat or sand at approximately 5°C has been found to be sufficient.

Seed is sown in early spring as soon as Mean Monthly Temperatures reach 11°C (maximum 16°C and minimum 6°C). The seeds are very small and young seedlings are prone to attacks by slugs and snails, so protection is necessary. Seed is sprinkled thinly over a standard seed-mix in trays, firmed down and covered very lightly with finely-sieved seed-mix (enough to hold the seed rather than to cover it. If this layer is too deep the seed will not germinate). Addition of a fungicide (e.g. Thiram) to the top mix layer will help to prevent damping off. Trays are placed in a warm glasshouse and watered to keep the seed-mix moist but not wet, and to prevent the surface from drying out. Under these conditions germination can be expected within 2 to 3 weeks.

Pricking out

Seedlings should be ready to transplant within 3 to 3 weeks of emergence. At this stage they will be about one cm tall and the first true leaves will have developed in addition to the heart-shaped cotyledons.

Each seedling is held gently by one leaf and prised out of the tray with the aid of a small spatula. Care should be taken to avoid damage to the fine and fragile roots. If too many are broken, the seedling will not survive.

Pricking out into nursery beds

Seedlings are usually transferred directly into mounded beds.

Reasons for this are:

- Root growth is very rapid and plants will quickly outgrow any normal container.
- Restriction of roots is likely to cause malformation and major growth problems.
- *Paulownia* does not grow well in artificial potting mixes. Seedling performance is much better under normal soil conditions. Perhaps this is a result of lack mycorrhiza in sterile potting mix or incorrect fertilizer balance?

Spacing at 50 cm will provide material suitable for transplanting during the following season, but for larger evenly sized plants, spacing of up to 1 m will be required. If grown too close in double rows spaced as , ' , ' , ' , ' , (alternate rather than opposite) some plants grow crooked to get to the light and some may be suppressed.

All that is needed after transplanting is conventional plant care with emphasis on weed control and protection from slugs and snails.

Figure 33: Four-month-old *Paulownia* plants in nursery beds

Pricking out into containers
(only if necessary)

The use of containers is not recommended as standard procedure; and is only necessary where conditions are unsuitable for direct transferring to the nursery. Use of plantable pots (e.g., paper pots or peat pots) will avoid inevitable damage to the fragile roots during transplanting. Pots should be filled with a standard potting mix and the seedlings placed carefully in a hole made with a spatula and then firmed in gently. Pots should be placed in a glasshouse and kept moist without excessive watering. Weekly application of water containing a low concentration of fungicide will help to avoid damping-off.

Seedlings pricked out into pots will be ready to transplant into mounded nursery beds within 3-5 weeks, when they are 5 - 8 cm tall. Due to rapid growth at this stage the stems of older plants may not be strong enough to stay erect if they grow taller than 80 cm. Soil should be well-cultivated and the beds should be protected from wind. Seedlings should be watered every 1-2 days for about 3 weeks, after which the frequency can be reduced. It is important to keep the ground moist until the roots become established. Rapid growth can be expected 4-6 weeks after transfer to nursery beds, with plants reaching heights between 1.5 and 5 m during the first season.

Weed control is important, especially during the first 8 weeks. Oxadiazon (Foresite 380) gives good control but must not be allowed to contact young tree foliage and should not be used for the first 2 weeks.

Growing from cuttings

Vegetative propagation of *Paulownia* by root cuttings is simpler and much more successful than methods which use stem cuttings. Many new plants can be produced from small quantities of root material.

Stem cuttings using softwood can be collected in November/December. Leaves are stripped from a shoot (adventitious shoots are best), and a sliver of hardwood with the cutting can improve its performance.

Root cuttings can be obtained from mature trees, or from plants in the nursery. Cuttings with a diameter of 0.75-2 cm and a length of 10-12 cm usually give consistent results. The timing of taking and striking cuttings is more important than their size. Larger root pieces do not always grow more vigorously. Cuttings may be taken during winter and stored under cool moist conditions, but better results are obtained by taking, preparing, and planting cuttings in early spring. In regions of New Zealand most suited to growth of *Paulownia*, early September is the optimum time. Root cuttings transferred immediately from the parent plant to nursery bed are less likely to suffer from dehydration or exposure to wind and strong sunlight.

Root cuttings from mature trees

Cuttings from mature trees never grow with as much vigour as those from juvenile roots. Use only mature trees for initial propagation from selected trees.

Dig a trench carefully around the base of the tree and excavate roots gently, for the required length. Suitable roots are 0.75-2 cm in diameter. Make a straight cut to sever the root at the end of the cutting nearest to the trunk, and a slanting cut 10-12 cm further away. The straight cut marks the upper end of the cutting and the slanting cut the lower end. Only a small number of cuttings should be collected from each tree. These can be used to produce nursery plants from which more root cuttings can be obtained in the following year.

Root cuttings from nursery plants

At the time of leaf-fall in autumn of the year after transfer of seedlings into nursery beds, the tallest, straightest, and most vigorous plants are marked with tags. Lift these as for planting in the field, retaining as much of the root system as possible. Prepare seedlings as described under lifting and take root cuttings as described above.

Treatment of cuttings

Root cuttings are washed, the fine lateral roots are trimmed off, and the main root is soaked for 30 min in a strong fungicide solution (Captan, Thiram, or similar). The cuttings are then laid on open trays to dry for at least 3 days in a ventilated glasshouse. At this stage they can be placed in a cool store until required.

Raising plants from cuttings in nursery beds

Cuttings should be set out to grow within two or three weeks of preparation, preferably in early September. They can be stored at about 5°C for up to 5 weeks, but this will reduce the strike rate.

Even after treatment with fungicide, saprophytic moulds may develop on cut surfaces. The root should always be cut back to clean wood before planting.

Root cuttings should be buried vertically in mounded-up rows in nursery beds protected from strong winds. The rows should be about 20 cm high, 40 cm across, and 80-100 cm apart. Cuttings should be spaced 50-100 cm apart. Spacing will dictate the size of the nursery product; at 100 cm the trees can be expected to reach a height of up to 6 m and a diameter of 7 cm in 1 year. Closer spacing will reduce height and diameter growth, as well as suppressing weaker cuttings.

Survival and growth are largely dependent on soil moisture, which must be adequate but not excessive. Irrigation during dry periods is essential until the plants are established.

Freedom from grass competition during the first few weeks and protection from slugs, snails, rabbits, and hares are vitally important.

Development during the first few weeks determines the first-year growth potential of the tree. With reasonable care the cuttings will grow strongly and will require little attention later.

Figure 34: Young *Paulownia* cuttings

Because plants grown from cuttings can be up to 5 m tall after 1 year, the lifting of such large plants for planting out can present problems unless they have been undercut. Undercutting should be done just before lifting.

In China it is common practice to remove all leaves from the plants at the time of undercutting. They are then lifted and transplanted to their permanent location without waiting until the following spring. This allows time for the hardening of stem tissue and repair to damaged roots during the 2-3 weeks that remain before the onset of winter. Plants are then well-prepared for productive growth as soon as favourable conditions return in the following spring. This practice has not been adopted in New Zealand, but might improve establishment rates here.

Dieback of the tops of freshly planted saplings has been a major concern for *Paulownia* growers. The trees grow vigorously during the later part of the growing season and, because there is little time for new tissue to harden before the start of the dormant period, the plants are vulnerable to frost damage and to bacterial and fungal attack. Only the youngest parts are affected, and buds often develop below the dead tissue. Care must be taken to see that only one of these becomes dominant. If two or more buds develop into leading shoots, the stem will be forked and the tree will have little timber value. Lateral branching should be encouraged for the production of a well-formed tree.

Raising plants from cuttings in containers

If the weather is too cool (Mean Monthly Temperature $<11^{\circ}C$) or the nursery bed is not ready, cuttings can be struck in paper pots or peat pots. Other types of container must be cut open to ensure that the plant is removed without damage to the delicate root system. The potting mix must be free-draining. A 3:1 coarse sand:peat mix containing powdered superphosphate (0.8 kg/m^3) and lime (1.0 kg/m^3) is recommended. Plant cutting with the slanted end down and the top end just below the soil surface. Hormone treatment is not necessary. Keep pots in a glasshouse, tunnel house, or a warm sheltered place outside, and water sparingly without allowing them to dry out. Bottom heat may be helpful but is not essential and can result in shock at transplanting due to temperature change. Also it can give the wrong type of spindly growth. Better results are usually achieved by not using it.

Once new roots and shoots have developed, usually about October, the plants can be lined out in the nursery. They should be watered immediately and then treated as if they were seedlings.

Lifting of root crowns or trees

Plants should be lifted and transferred to the field at the very end of the winter season. Earlier planting may result in losses caused by fungal attack while the tree is still dormant. If the nursery is close to the planting site and trees have been spaced about 1 m apart, sturdy plants with a 20-30 cm-diameter root ball can be dug out and planted directly. It is probably easier to transfer plants grown at closer spacings. Plants can be lifted as full trees (see note above re dieback) or as root crowns (easiest).

Key Points

- *Paulownia* can be grown from seed and cuttings
- Root cuttings are the preferred source of cutting material
- Raising plants or cuttings in raised nursery beds is preferred over raising planting stock in containers
- Quantities of root cuttings are best taken form selected nursery stock but small numbers can be collected from high quality, mature trees.

Additional reading:

Ede (1993)

Zhu *et al.* (1986)

CHAPTER 7 - ESTABLISHMENT

The optimum time for planting out nursery-grown *Paulownia* in New Zealand is late winter/early spring, just before growth recommences.

Clay soils

If the soil is at all heavy, planting rows should be ripped to a depth of at least 80 cm with double tines spaced about 1 m apart.

Grassed sites

Grassy areas should be spot-sprayed at least 3 weeks before planting. Spots should be at least 1.5 m in diameter. The herbicide should be capable of knock-down and long-term weed control for at least 9 months.

Scrub-covered sites

The area must be cleared before planting and any regrowth must be rigorously controlled.

Spacing

The trees can be established at final stocking rates. Recommended spacing is 7 x 7 m for plantations (204 stems/ha) and 5 m for single row shelter belts. Wider spacing results in faster initial growth, which may reduce the value of the timber. Closer spacing will reduce growth rates over the first 3-4 years. Alternatively, trees can be planted at 7 x 3.5 m spacing (408 stems/ha) and thinned out later to provide an intermediate timber crop.

Planting procedure

If the ground has not been ripped, planting holes should be as large as possible - in heavier soils at least 30 x 30 x 30 cm. For planting single trees, the hole should be half-filled with friable soil (mixed with fertiliser, if required) and the plant placed so that the junction between root and stem will be about 1 cm below the final soil level. Remaining soil is then replaced and firmed with the foot. On flat land, especially if there is danger of soil saturation in winter, it is recommended that a planting mound be raised so that the final level of the soil in planting holes is 30 cm above the surrounding soil surface.

Irrigation

Watering will be required if rainfall during the first growing season (November to April) is less than 100 mm per month. As a rough guide, 10 mm of rainfall supplies about 100 litres of water. Irrigation will also be required in subsequent years if monthly rainfall falls below 50 mm. Inadequate water supply slows growth, but does not cause mortality.

Post-planting weed control

Weed control promotes maximum growth and tree health. A circle 1.5 m in diameter around each tree should be kept free of weeds for at least 2 years. Spraying should be carried out in spring just before growth recommences, but care should be taken to see that the spray does not contact the tree stem. Any shoots sprouting from damaged roots around the tree should be removed manually, and not with herbicide.

Shoot reduction

Root cuttings will produce new shoots from about mid-September. These should be allowed to grow until they are about 50-60 cm long, when all but the most vigorous shoot should be removed.

ESTABLISHMENT TRIAL

A trial to identify critical planting procedures and management practices for establishing *Paulownia* was planted in the Bay of Plenty in 1993 (Figure 35). Nine different treatments were established with 6 replications. After 2 years it was not unexpected to find that the maximum input treatment (cultivation, weed control 2 years, fertiliser 2 years) was showing the best results. Overall the most important factor was weed control rather than fertiliser (E. Hay pers comm.).

Figure 35: Establishment trial, Bay of Plenty, showing the effect on tree growth and survival of a range of treatments

Key Points

- Site preparation is critical for satisfactory growth
- Weed control is the most vital aspect of site preparation
- Irrigation is advantageous if summer rainfall is inadequate
- Initial spacing of 7 x 7 m (204 stems/ha) is recommended
- Shoots from root cuttings require thinning leaving the most vigorous.

Additional reading:

Ede (1993) Zhu *et al.* (1986)

CHAPTER 8 - PESTS AND DISEASES

Although several organisms are known to attack *Paulownia* in China, there do not seem to be many problems with pest and diseases in this country. There are no organisms that target *Paulownia* specifically, but young plants are vulnerable to attack by common pests such as damping-off fungi, nematodes, cutworms, and snails.

Pests

The following insects have been observed on *Paulownia* in New Zealand:

Aenetes virescens (Ghost moth) – a stem borer

Kalotermes brouni (A native dry wood termite) – found in dead branches

Oemona hirta (Lemon tree borer) – bores into small branches.

None of these causes serious damage. Attacks by ghost moth are common in some areas, mainly where there is undergrowth. This insect is not present in the South Island.

There are unconfirmed reports of defoliation associated with the adult form of grass grub (*Costelytra zealandica*).

Some instances of possum (*Trichosurus vulpecula*) damage have been recorded, but these seem to have been associated with play, rather than with browsing.

Figure 36: Example of witches' broom in China

Diseases

Two fungi of very minor importance to *Paulownia* are:

Fusarium merismoides – causing twig dieback

Phoma macrostoma – a leaf spot fungus.

Loss of a specimen tree to *Armillaria*, the “bootlace fungus” has been reported by Ede (1994). Recent deaths in the Bay of Plenty have been attributed to *Armillaria*. This fungus attacks the roots and lower stems of a large number of tree and shrub species in New Zealand.

A “witches’ broom” disease attacking *Paulownia* trees of all ages is a major problem in China. It is caused by a microscopic organism called a phytoplasma which can only be transferred in vegetative material. For this reason it is vitally important that seed should be the only *Paulownia* material imported into New Zealand.

Key Points

- Ghost moth can cause damage on some North Island sites
- Armillaria can cause mortality in some stands, but is not common
- The most serious health problem in China is “witches’ broom”
- Vegetative material should not be imported from China to avoid any risk of importing witches’ broom.

Additional reading:

Zhu *et al.* (1986)

Ede (1993, 1994)

The aim of good silvicultural practice is to produce a crop of trees with good form and healthy growth. This is done by careful removal of malformations. If timber is required as an end-product, the encouragement of development of the maximum amount of knot-free wood in the trunk is an additional objective. This can be achieved by removing branches that are not essential for the maintenance of optimum levels of photosynthetic activity.

The sprouting of new shoots from the trunk is a reaction to stress. It is a mechanism for increasing the leaf area of the tree and may occur at any stage. Unwanted shoots should be removed, and the source of stress should be determined and alleviated wherever practicable.

Elongation pruning (form pruning)

Elongation pruning is carried out to encourage development of a trunk at least 6 m long before crown formation is allowed. On good sites this can be achieved in 2 years; elsewhere 3 years will be needed.

In some *Paulownia* species, notably *P. fortunei*, the strongest shoot tends to dominate and the stem is unlikely to fork. In most other species elongation pruning will result in the development of a longer, straighter, and stronger leader.

The first operation is carried out in the spring shortly after the trees have been transferred from the nursery (this does not relate to material planted as root crowns), when the new buds are about 2 cm long. The strongest pair (second to fourth from the top, depending on species) is selected and a diagonal cut is made across the node so that one bud (preferably on the leeward side) and the top of the tree are removed (Figure 37). The trees should be examined every 2 to 3 weeks during the following 2 months so that any vigorous lower branches that might overtop the leader can be shortened. If the selected leader fails, the pruning process can be repeated with another vigorous shoot.

Figure 37: Elongation or form pruning. A diagonal cut is made so that the strongest bud will develop into the new leading shoot.

The elongation pruning procedure is repeated in the second and, if necessary, the third year after planting. A pole pruner will be required at this stage.

Any lateral branches with butt diameters greater than 3 cm in November should be cut back to half length (Barton 1995b). This will reduce diameter growth and make the spring pruning much easier.

Lateral pruning

Pruning of lateral branches reduces the size of knots which can spoil the quality of timber in the trunk. It is carried out on final crop trees in three separate operations and is usually done in the autumn to minimise the formation of substitute branches. If new branches do sprout they should be rubbed off by hand as soon as possible.

The first operation is carried out 2.5 years after planting, providing that the trees are more than 4 m tall. All branches are removed from the bottom third of the main stem, and any other branches with butt diameters greater than 3 cm cut back to one-third length.

The second pruning operation is carried out 12 months later on trees that are more than 6 m tall. Lateral branches below half tree height are removed and higher branches with butt diameters greater than 3 cm are cut back to one-third length.

The final pruning takes place when the trees are 4.5 years old. At this time they should be almost 12 m tall. They are pruned to half height, leaving a pruned trunk length of 6 m. Pruning of individuals that are less than 8 m in height should be deferred for another year.

Coppicing

Trees with poor initial growth can be rejuvenated by coppicing. *Paulownia*, like many other deciduous species, reacts to removal of the trunk by forming new and very vigorous shoots. This occurs at any point of removal whether at ground level or higher.

Trees should not be coppiced for at least 2 years after transfer from the nursery. This ensures that the root system is well-developed. At the end of the second or third winter, just before growth is due to start, the stems of poorly-shaped trees are cut off at ground level. Several shoots will develop and all but the most vigorous one should be removed in October. Regrowth is fast and the shoot will be straight unless it is affected by wind. Height growth during the subsequent season should be equal to that in uncoppiced trees. Elongation and lateral pruning are carried out as described above.

Pollarding

Rejuvenation of trees with poor initial growth can also be achieved by pollarding. This operation is carried out on trees which have a straight trunk 2-5 m long. The crown is removed at a point that will leave the maximum trunk length. When new shoots develop, the topmost one is selected as the new leader. All of the lower branch sprouts are removed. Although the trunk will have an initial kink, this will straighten out within 3 years (Barton 1991).

Thinning

Trees planted at final spacing will not require any thinning apart from the removal of an occasional underdeveloped individual. Where trees have been planted more closely, two options for maximising timber productivity in the final crop can be recommended:

1. Maintain spacing for 5-6 years after transfer from the nursery in order to slow initial diameter growth and minimise branch size. When the pruning of final crop trees has been completed, remove unwanted individuals to leave a final stocking of about 200 stems/ha. Nurse plants (if present) should be removed at the same time.

2. If an intermediate timber yield is one of the objectives, approximately 400 stems/ha should be pruned. If there are more than 400 stems/ha, remove surplus trees at age 5 years.

When the mean stem diameter reaches about 40 cm (at approximately age 15) harvest half of the stand. Remaining trees are left until about age 25.

The following Table recommends the timing of operations for the establishment and early maintenance of a *Paulownia* plantation.

Operation	Tree age (yr)	Month/season	Procedure
Nursery practice	-0.8	October/November	Seedlings or root cuttings planted out into nursery beds at 50 cm spacing.
	-0.1	August	Plants lifted and trimmed to form root crowns which are dipped in fungicide solution and dried for 4 days at air temperature unless planted immediately.
Site preparation	-0.1	July	Spray 1.5-m-diameter circles with herbicide (glyphosate/Simazine mixture, or similar product). Space circles at 7 x 7 m for plantations or 5 m for single rows.
Planting	0	August	Dig large holes (in heavier soils at least 30 x 30 x 30 cm). Replace soil (mixed with fertiliser if required - see next operation) to half-hole depth. Plant root crown so that top is 1 cm below soil surface. Make sure soil is well firmed.
Fertiliser treatment	0	August	On most sites fertiliser will not be needed. Elsewhere use NPK formulation with high N level at a rate of 200 g/tree, mixed with soil in the bottom half of the planting hole.
Shoot reduction	0.3	October-November	Reduce number of shoots to one, preferably located on windward side to reduce wind breakage.
Releasing	0.5	Late spring	Spray with herbicide if weed regrowth is present. Do not allow spray to contact the trees.
Watering	0.7	December - April	If rainfall is insufficient (trees require 100 mm or /month), water fortnightly. 100 l/m^2 = approx. 100 mm of rainfall.
Releasing	1	August	Before new growth begins, spray a 1.5-m-diameter circle round each tree with herbicide. Do not allow spray to contact the trees.
Elongation pruning	1.1	September-November	Select strongest pair of buds (usually second node from top in *P. tomentosa, P. elongata,;* fourth from top in *P. fortunei* and *P. fargesii*). Cut diagonally across node to remove tree top and one bud. (Fig 37) Where possible leave bud on windward side. Check every 2 weeks to remove any lower branch that could overtop selected leader. If leader fails, repeat the operation at a lower point on stem.
Watering	1.7	December - April	Water as for first year after planting.
Releasing	2	August	Before new growth begins spray a circle 1.5 m in diameter around each tree with herbicide. Do not allow spray to contact the trees.

Operation	Tree age (yr)	Month/season	Procedure
Coppicing	2	August	Remove any trunks that are not potentially millable by cutting at ground level.
Elongation pruning	2.1	September - November	As for elongation pruning at end of first year.
Shoot reduction	2.3	October-November	Recent coppicing only. As for shoot reduction in first year.
Form pruning	2.3	October-November	Reduce lateral branches with butt diameter greater than 3 cm to one-third length.
Irrigation	2.7	December - April	As for irrigation in first year.
First lateral pruning	2.6	March-April	Remove branches up to one-third of stem height. Reduce remaining branches with butt diameter greater than 3 cm to one-third length.
Elongation pruning	3.1	September - November	As for elongation pruning at end of first year, but only on trees less than 5 m tall.
Second lateral pruning	3.6	March-April	Remove branches up to one-half of stem height. Reduce remaining branches with butt diameter greater than 3 cm to one-third length.
Third (final) lateral pruning	4.6	March-April	Remove branches to final trunk height of 5 - 7 m.
Side shoot pruning	2 - 8 years	Spring/summer	Remove any side shoots developing from the main trunk as soon as possible.

The following comments should be borne in mind:

- In sheltered, fertile nursery sites seedlings can be grown at 1 m spacing and transplanted as rooted poles when at least 4 m tall. They must be planted within 1 week of lifting.
- Seedlings can be grown in containers during the summer prior to planting or lining out in the nursery if required. Damage to roots must be avoided.
- Closer spacing is thought to result in better tree growth and form.
- On flat land, especially where drainage is poor, it is recommended that trees should be planted on mounds raised about 30 cm above surrounding ground level.
- Weed control is a vitally important factor in plantation management. A 1.5-m-diameter circle around each tree should be kept clear of vegetation for at least two growing seasons.
- Unpublished results from trials in the Waikato indicate that excellent growth was obtained from mulching with 30 litres of mushroom compost per tree. Mulching reduces the need for spraying with herbicide. Mulch should not be allowed to contact the tree trunk.
- Although some *Paulownia* species, especially *P. fortunei*, may not require elongation pruning, this operation usually produces stronger and longer leaders.

Key Points

- *Paulownia* requires corrective pruning to produce good sawlogs
- Corrective pruning is required during the first 3 years after planting
- *P. fortunei* has stronger apical dominance than other species
- Pruning for clearwood is necessary, remove no more than half the green crown
- Remove any epicormic branches soon after they appear.

Additional reading:

Barton 1991

Barton 1995b

Zhu *et al.* (1986)

CHAPTER 10 - GROWTH AND YIELD

Little is known about the growth rate and timber productivity of plantation-grown *Paulownia*. One small plantation near Xian in China was expected to yield about 100 m^3/ha when harvested at age 10 years. Chinese sawmills indicated an average log size of 0.6 - 0.7 m^3 at age 7 - 10 years.

Areas of China in which "Forest Net" systems have been established appear to support about 10 - 15 m^3/ha of *Paulownia* of which 1 - 2 m^3/ha may be harvested in any 1 year (see Chapter 2 *Paulownia* in China). Total *Paulownia* stocking in these areas averages about 15 - 20 trees/ha.

Paulownia growth in Japan appears to be relatively slow when compared with growth rates in China. Mean annual increment at stocking rates of 380 - 750 stems/ha is about 18 m^3 (Yamazoe *et al.* 1979).

In Australia, Jay (1992) suggested that a double-row *Paulownia* shelterbelt containing 200 stems/km would yield 300 m^3/km at age 20. He also predicted that an agroforestry grazing regime of 80 *Paulownia* stems/ha would produce about 75 m^3/ha at age 20.

In the USA the expected average yield from 40-year-old *Paulownia* plantations is 250 - 275 m^3/ha. Expected mean tree volume is about 2 m^3 with dbh averaging 67 cm (Graves 1997).

In Brazil growth is rapid and increments of 11 - 30 m^3/ha/annum, depending on site, have been obtained (Yamazoe *et al.* 1979).

There are insufficient data collected in New Zealand to predict *Paulownia* growth rate or timber yield in New Zealand with any degree of confidence. Some of the limited comparable data collected in the mid 90s are shown in Table 2. On favourable sites, trees have reached a maximum dbh of 37 cm in 5 years.

In some older plantations there has been a slowing of annual increment after about age 5. This may be related to heavier soil texture. Trees (thought to be *P. fortunei)* grown on Hunua Yellow-brown Clay soil had a mean annual diameter increment (MAIdbh) of just over 5 cm during the first five years. This was slightly lower than the 6.5 cm recorded on the more friable Yellow–brown Pumice soil at Te Puke. Slower growth of (*P. elongata*) trees on friable loam soil at Otaki (MAIdbh 4.6 cm to age 5) is probably attributable to the closer spacing in this plantation. At Hunua the MAIdbh had dropped to 3.8 cm by age 10.

Best estimates of growth at present are based on data from a few well-sited and well established plantations. In the mid 1990s these were assessed for growth (Table 2). Volumes were calculated using standard log volume formula. Log taper was not included in these calculations. Using MAI, data estimates were made of stand age to produce trees of approximately 0.75m^3/tree. It is expected that a target dbh of 70 cm will be reached at about 20 years on clay soils and 12 years on well-drained, loamy soils. At harvest these stands might be expected to carry 200 stems/ha and have a volume of 150 m^3/ha.

Key Points

- There are limited growth data for New Zealand-grown *Paulownia* stands
- Possible yields of 150m^3/ha from 200 stems/ha are suggested
- Rotation lengths to achieve 70 cm dbh trees at 12- 20 years are suggested

Additional reading:

Xihong (1990)
Jay (1992)
Zhu *et al.* (1986)
Graves (1997)
Yamazoe *et al.* (1979)

Table 2: Growth rates of *Paulownia* in plantations in New Zealand.

Reputed species and provenance	**Location**	**Age** (yr)	**Pruning treatment** (*, #)	**Total height** (m)	**Merchantable log length** (m)	**Dbh o.b.** (cm)	**MAI dbh** (cm)	**Volume i.b.** (m^3)	**MAI volume** (m^3)	**Est. age to volume of ca 0.75 m^3** (yr)
P. fortunei "Bola"	Hunua	10	*	11.50	4.8	37.7	3.8	0.4386	0.0439	17
P. fortunei "Bola"	Hunua	5	*	7.70		26.5	5.3			
P. fortunei "Zhejiang"	Te Puke	5	*	11.25	5.5	33.9	6.8	0.3663	0.0733	10
P. fortunei "Zhejiang"	Te Puke	5	*	11.75	5.3	30.7	6.1	0.3076	0.0615	12
P. fortunei "Zhejiang"	Te Puke	5	*	11.50	4.7	32.7	6.5	0.2776	0.0555	14
Means for *P. fortunei* at Te Puke		5		11.50	5.17	32.45	6.5	0.3172	0.0634	12
P. elongata "197"	Hunua	10	*	11.25	4.8	37.6	3.8	0.4327	0.0433	17
P. elongata "197"	Hunua	5	#	9.25		26.2	5.2			
P. elongata "197"	Hunua	5	#	10.85	4.3	37.8	7.6	0.3751	0.0750	10
P. elongata "197"	Te Puke	5	*	11.00	4.5	36.0	7.2	0.3543	0.0709	11
P. elongata "197"	Te Puke	5	*	10.00	4.3	34.0	6.8	0.3253	0.0651	12
P. elongata "197"	Te Puke	5	*	10.75	4.9	31.2	6.2	0.2800	0.0560	13
P. elongata "Avery"	Te Puke	5	*	10.75	5.4	27.4	5.5	0.2419	0.0484	16
Means for *P. elongata* at Te Puke		5		10.67	4.68	33.50	6.7	0.3153	0.0631	12
P. elongata "Avery"	Otaki	6	*	11.00	5.2	28.0	4.7	0.2463	0.0411	18
P. elongata "Avery"	Otaki	6	#	10.25	5.4	27.1	4.5	0.2388	0.0398	19
Means for *P. elongata* at Otaki		6	#	10.63	5.30	27.60	4.6	0.2426	0.0404	19

* Minimal pruning from below
\# normal pruning

AGROFORESTRY IN NEW ZEALAND

Although no trials have been attempted, there seems to be no reason why maize could not be grown with *Paulownia* shelter on the alluvial river flats of the North Island east coast. Productive use of areas which are too steep for large-scale mechanical cultivation might be increased by planting single rows of *Paulownia* to hold the soil.

Figure 38: *Paulownia* shelterbelt on Waikato Dairy farm.

The use of *Paulownia* shelter in areas grazed by sheep has been tested on a small scale at Hunua and shows considerable promise, although no data on yields or carrying capacity have been calculated. Trees are planted at 5-m intervals in rows that are spaced about 20 m apart (100 stems/ha). They are protected with electric fencing (Figure 39). On dairy farms it should be possible to grow single rows of *Paulownia* trees spaced at 5-m intervals on paddock boundaries, with electric fences to control the animals. Up to 0.5 ha of grazing would be forfeited for every kilometre of shelter, but this would be offset by benefits from changes in local microclimate and the recycling of plant nutrients in *Paulownia* prunings and leaf fall.

OTHER USES FOR *PAULOWNIA*

Other than traditional forestry uses for timber, *Paulownia* can provide many other useful products, which makes it attractive in an agroforestry setting, as single trees, in shelterbelts, or in plantations.

Honey

Paulownia is reputed to be a good nectar producer but there is little published information. Xiong (1990) reports that a single hive produces 10–15 kg of honey during the *Paulownia* flowering season.

Medicinal

Paulownia has long been used in traditional Chinese medicine but there seems to have been little modern analysis of the potential of the genus in this area. Zhu *et al.*, (1986) report that the leaves contain ursolic acid ($C_{30}H_{48}O_3$), matteucinol ($C_{18}H_{18}O_5$); the xylem paulownin ($C_{20}H_{18}O_7$); CH_3OH), d-sesamin; the bark syringin ($C_{17}H_{24}O_9$; H_2O), and catalpinoside. As well the fruits contain acid, fatty oils, flavanone, and alkaloid.

Fodder

Analysis of the feed value of *Paulownia* reveals that the above-ground parts contain high levels of useful nutrients. (Table 3).

In China pigs and poultry have been fed, experimentally, with *Paulownia* leaves. Providing not more than 15% (dry weight) of *Paulownia* leaves is added to the pig feed, there is no significant weight loss. This means a reduced amount of the more valuable wheat bran is needed for the food mix (Xiong 1990).

With poultry it has also been demonstrated that a feed mix containing 19% dried *Paulownia* leaves will increase egg production by 3.3% and egg weight by 1.7% (Xiong 1990).

Figure 39: Electric fence protection of small scale agroforestry block.

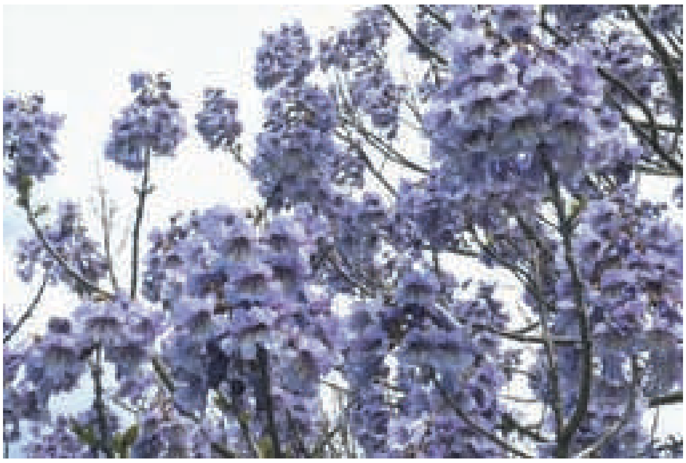


Figure 40: *Paulownia* with heavy flower crop

Figure 41: *Paulownia* leaves, a potential fodder crop

Table 3: *Paulownia* foliar nutrient levels in New Zealand and China

ELEMENT	*Species* Seed Origin Tree Origin Tree Age Tree Part Source	*P. tomentosa* Beijing Hunua 2 years Mature leaves (a)	*P. fortunei* Zhejiang Hunua 2 years Mature leaves (a)	*P. tomentosa* NZ Tirau 30-40 years Mature leaves (b)	*P. tomentosa* NZ Tirau 30-40 years Mature buds (b)	*P. tomentosa* Japan Hamilton 1 & 2 years Mature leaves (c)	*P. elongata* China China 5 & 6 years Mature leaves? (d)
NITROGEN	% Dry Wt	1.869	1.632	2.08	1.04	2.67	2.51
PHOSPHORUS	% Dry Wt	0.118	0.164	0.15	0.22	0.25	0.18
POTASSIUM	% Dry Wt	0.838	0.972	1.2	2	1.24	0.85
MAGNESIUM	% Dry Wt	0.100	0.153	0.17	0.1	0.2	0.82
CALCIUM	% Dry Wt	1.665	1.647	1.35	0.11	1.45	2.2
SULPHUR	% Dry Wt	0.130	0.148	0.15	0.08	0.19	
ALUMINIUM	ppm	174	309				248
ARSENIC	ppm	1.176	1.25				
BORON	ppm	62.3	56.3	33	14	31	31.8
CADMIUM	ppm	0.6	0.657				
COBALT	ppm	LOQ	LOQ				1.66
CHROMIUM	ppm	LOQ	LOQ				1.35
COPPER	ppm	6.5	9.89	11	16	18	14.6
IRON	ppm	57.3	88.6	139	57	182	600
MANGANESE	ppm	51.5	83	67	7	37	109
MOLYBDENUM	ppm	0.1	0.097				
SODIUM	ppm	225	292	300	600		360
NICKEL	ppm	LOQ	LOQ				0.91
LEAD	ppm	LOQ	LOQ				1.58
STRONTIUM	ppm	29.6	41				
VANADIUM	ppm						1.05
ZINC	ppm	24.5	35.2	65	38	39	27.5
DRY MATTER	% Dry Wt						
CRUDE PROTEIN	% Dry Wt	11.68	10.2				16.96
MAD FIBRE	% Dry Wt						11.75
FAT	% Dry Wt	3.84	3.34				6.33
ASH	% Dry Wt						5.49
SUGAR	% Dry Wt					14.2	7.48

(a) Crop & Food: (b) R J Hill (1997): (c) Ede (1993: (d) Xiong (1990)

Key Points

- *Paulownia* has potential for horticultural and agricultural shelter
- *Paulownia* can be considered for honey production and for medicinal uses
- *Paulownia* foliage can provide useful fodder.

Additional reading:

Ede (1993), Zhu *et al.* (1986), Xiong (1990), Hill (1997)

CHAPTER 12 - TIMBER UTILISATION AND MARKETING

Paulownia timber is widely used in Asia. It is light, odourless, and easily worked. In colour it varies from silver-grey (highly prized in Japan) to light brown. It has a low basic density but is easy to dry and, although unsuitable for structural use, has physical and mechanical properties that are acceptable for other purposes. It is straight-grained and easy to plane to a glossy surface. Overseas reports indicate that it has good natural durability, but results in New Zealand suggest that it should be classified as non-durable (Barton and Nicholas 1991). The pale brown heartwood is difficult to distinguish from the slightly lighter sapwood, which is only found in the outer 1-2 annual rings.

Characteristic features are:

- Lightness – *Paulownia* is the lightest known timber other than balsa.
- High strength-to-weight ratio (although basic strength is low).
- Low shrinkage potential.
- Very stable structure.
- Resistance to insect damage.
- Low thermal conductivity.
- Low temperature conductivity.
- Good electrical insulation properties.
- Resistance to fungal rots but not to surface moulds.

Table 4. Characteristics of *Paulownia* wood samples tested at the New Zealand Forest Research Institute.

Supposed species	Source	Approximate age (yr)	Dbh (cm)	Density (kg/m^3)	Heartwood (%)
P. tomentosa *	Rotorua	22	35 (approx)	247	92
*P. elongata**	Te Kuiti	13	55	270	78

* full identification not confirmed.

Air-dry wood density in Rotorua-grown *P. tomentosa?* was 350 kg/m^3, slightly higher than the very low value of 277 kg/m^3 recorded for *P. fargesii* wood grown overseas. Basic wood density was also higher (295 kg/m^3 in the Rotorua sample compared with 236 kg/m^3 for *P. fargesii*).

Wood properties of six *P. tomentosa?* trees (two from Rotorua, one each from Hastings, Hawke's Bay, Pirongia and Hamilton) and three *P. elongata?* trees (one from Rotorua, two from Hamilton) were investigated at the New Zealand Forest Research Institute. Tree age ranged between 4 and 25 years. Comparisons with data for Korean-grown *P. tomentosa* (Table 5) suggest that New Zealand wood is slightly denser.

New Zealand-grown *Paulownia* species had similar air-dry strength properties (modulus of rupture 40-41.3 MPa, modulus of elasticity 4.0-4.1 GPa).

Uses

Paulownia wood has been used for a wide variety of purposes in China and Japan for more than 2500 years (Hu 1959, Zhu *et al.*, 1986). The main products are:

- Housing components requiring lower timber strength.
- Aircraft fittings requiring light wood.
- Veneers for plywood and for facing lower quality wood.
- Furniture, especially drawers. This is because the wood fits snugly and is insect-resistant. In Japan it is used to make tonsui (dowry chests).
- Musical instruments, particularly sounding boards.
- Barrels, especially those used for acids, wine, etc.
- Beehives, for which light-weight and good insulating properties are needed.
- Aqueducts, in rural areas.
- Handcrafts, because the wood is easy to carve and turn.
- Rice bowls and other utensils, especially in earlier times.
- Wooden boxes for gifts or storage of paintings and scrolls.
- Charcoal for fireworks and filters.
- Wood pulp – which is white and strong.
- Wood shavings for packaging and insulation.
- Packaging, especially light crates.
- Coffins (an ancient use in China).
- Pattern-making, where timber stability is required.

In New Zealand *Paulownia* is most likely to be used in the manufacture of veneers and furniture.

Figure 42: Furniture made from New Zealand-grown *Paulownia*

Figure 43: Veneer made from New Zealand-grown *Paulownia*

Figure 44: Turned items made from New Zealand-grown *Paulownia*

Table 5. Comparison of wood properties of New Zealand-grown and Korean-grown *Paulownia* with those of some other well-known timber tree species (Source: (FRI 1992).

	Paulownia			**Balsa**	**Radiata pine**
	New Zealand		**Korea**		
	elongata*	***tomentosa****	***tomentosa***		
General					
Basic density (kg/m^3)	285	300	-		
Air-dry density (kg/m^3)	335	340	240		
Green moisture content (% air dry wt.)	215	170	139		
Shrinkage to air-dry (%)					
Tangential	1.8	2.0	3.3		
Radial	0.8	0.9	2.5		
Stability					
Equilibrium moisture content at 90% Relative Humidity (%)	22		-	21	21
Equilibrium moisture content at 60% Relative Humidity (%)	8		-	11	12
Long-term movement when RH raised from 60 to 90% (%)					
Tangential	2.1		-	2.0	2.0
Radial	1.3		-	0.6	1.0
Unit shrinkage per 1% moisture content change (%)					
Tangential	0.15		0.21	0.20	0.22
Radial	0.09		0.15	0.06	0.10
Air-dry strength					
Moisture content (%)	11.0	10.8	12.0	12.0	12.0
Modulus of rupture (MPa)	41.3	40.0	43.7	23.0	89.9
Modulus of elasticity (GPa)	4.1	4.0	na	3.2	9.0
Compression parallel (MPa)	22.4	23.7	15.2	15.5	38.1
Shear parallel (MPa)	5.3	5.7	-	2.4	11.9
Hardness (kN)	1.4	1.3	-	na	4.2

* full identification not confirmed.

Durability

Interest in *Paulownia* timber in New Zealand has been stimulated by timber imports from China and the development of a fledgling *Paulownia* industry in Australia. One of the topics under discussion is the natural durability of the timber, with some confusion existing about the durability rating of *Paulownia* species. A review of local and overseas literature has produced contradictory evidence.

The work of Zhu *et al.* (1986) has been used as a major authority on *Paulownia* during recent years. It is often quoted by timber entrepreneurs and contains the following statement about resistance to organisms causing wood rots:

> *"Systematic research on rot resistance of Paulownia wood has not been done yet. It has, however, been reported that Paulownia wood is highly rot resistance [sic?] and the rot is only superficial. Clean, white wood appears when the surface is planed. In Luengchou, Kwangsi Autonomous Region, a tropical area where wood rots easily, we saw some Paulownia boards which had been soaked in water for ten years and used to make a coffin which lasted more than 30 years without decay. A coffin made of Paulownia wood more than 200 years ago was unearthed in Luechan County, Hupeh province and was found to be in good condition. In addition, from the Szechuan Provincial Research Institute of Forestry, in Hong Ya Forestry farm, it was reported that Paulownia and many other tree species were left in the forest following felling. After 15-16 years, the other trees were completely rotten but Paulownia wood only decayed around 1 cm depth on the surface. However, experiments by the Chinese Academy of Forestry produced a conflicting result that Paulownia wood is not rot-resistant. More data is required."*

In the draft of his report on a visit to China in 1991, Ian Barton noted:

> *"One question raised was on the durability of Paulownia. Prof Zhu quoted several anecdotal examples; eg, a 200 year old coffin from a very wet area (1800 mm rainfall), logs left lying in the forest and not rotting etc. They have also done rapid decay tests and seem to get similar results to us; ie, fairly fast decay. They do not seem to have fully got to grips with this problem yet but Prof Zhu feels that for some unexplained reason, artificial testing may not accurately reflect the field situation. Paulownia has reasonabley good resistance to borer etc and falls about midway in its resistance to termites, white ants etc. There is apparently no difference between regions/species in Paulownia's resistance to decay".*

The New Zealand Forest Research Institute seems to have produced the only published set of results comparing the in-ground performance of *Paulownia* stakes with that of other benchmark timber species. Unfortunately the samples were taken from a limited number of trees, and although the results were supported by laboratory tests, it is not possible to draw definite conclusions from the data. Some overseas reports tend to confirm the findings while others contradict them. The uncertainty will continue until further research has been carried out on the durability of timber being sold in New Zealand.

MARKETING

Japan appears to be the largest importer of *Paulownia*. Both sawn and roundwood timber are obtained from overseas. Japan utilised a total of 185,000 m^3 of *Paulownia* in 1990 and about 90% of this had been imported. In 1992 consumption appeared to be increasing (prior to 1970 only about 50,000 m^3 were used annually).

Paulownia wood comes mainly from China, with Taiwan, Brazil, and USA contributing smaller amounts. Only USA can supply high quality timber. In 1990 the average price paid in Japan for logs from USA was ¥217,000/m^3 (round) while those from China realised only ¥47,000/ m^3 (round). This is a direct reflection of the high value placed on slower-grown *Paulownia* which has a more desirable colour and texture.

Japanese *Paulownia* plantations have been reduced in area during recent years due to pressure from alternative land use. In 1990 only 6 000 ha remained of the 10,000 ha recorded in the early 1980s.

In the USA, supplies of naturalised *Paulownia* appeared to be running low in the 1980s after a boom in exports which began in 1975 (Hemmerly 1989). American growers are apparently looking to establish more plantations in order to develop their profitable trade in the timber (Graves 1997).

There is no guarantee that exporting countries will continue to find a ready market for *Paulownia* in Japan unless they satisfy requirements at the upper end of the market. Of the present growers, only USA and possibly New Zealand appear to have capability for supplying this demand.

New Zealand seems to be well-placed for taking advantage of the Japanese market if it can supply timber of a suitable quality. This may mean an increase in initial stocking to slow the growth rates. Research into the properties of timber from recently established plantations has yet to be undertaken. This work is essential for the production of convincing evidence about the potential of New Zealand-grown wood.

Internally, the New Zealand market has not shown interest in the potential of *Paulownia* timber. Small trials indicate that New Zealand-grown wood could have a role in the manufacture of furniture (FRI 1992). Sliced and peeled veneers show some promise and may be superior to radiata pine for some purposes (L. Jelinek, pers. comm.), although more research on these products is required. Comparative prices paid for timber in Japan give an indication of the value of *Paulownia* wood. Between 1972 and 1990, radiata pine lumber was worth ¥17 000 - ¥28 000/m^3. *Paulownia* prices over the same period ranged from ¥59 000 to ¥120 000/m^3. The value of *Paulownia* was 3.5 - 7.7 times greater than that of radiata pine, the average difference being 5.8 times higher (B. Glass, pers. comm.).

Key Points

- *Paulownia* is a light stable timber
- The in-ground durability of *Paulownia* timber is unclear
- *Paulownia* is used for many purposes in China and Japan
- *Paulownia* timber has a strong but small market niche in Japan.

Additional reading:

Barton and Nicholas (1991)

Clifton (1990)

FRI (1992) and FRI (1997)

Haslett *et al.* (1992)

Hemmerly (1989)

Hu (1959)

Olsen and Carpenter (1985)

Pohleven and Petric (1997)

Takahashi and Nishimoto (1973)

The Forestry Research Institute of Seoul (1988)

Zhu *et al.* (1986)

Glass (1992)

Because of its limited adaptability to different site conditions, *Paulownia* may never be an economically important tree species in New Zealand. Plantations in favourable locations may offer some opportunities for exporting timber. The greatest potential probably lies in agroforestry, where single-row plantings can provide useful shelter surrounds for dairy paddocks and market gardens, or in small woodlots complementing other land uses. With its prolific flowering habit it also warrants planting for amenity alone.

Figure 45: Shelter and amenity planting of *Paulownia* in the Waikato

Paulownia timber can be used in the manufacture of high-grade boxes, veneer, and furniture. The potential of different *Paulownia* species as a source of fodder, biofuel, chemical extractants, and honey production has not been investigated, but may be of interest in the future.

The planting of *Paulownia* in Australia, largely through investment schemes, has seen the establishment of plantations in Western Australia, New South Wales, and Queensland. These have been managed almost like a horticultural crop with irrigation systems, etc. The success of these plantations is yet to be determined, although some companies' efforts in utilisation and marketing may see the development of an Australasian market.

Figure 46: *Paulownia* can grow well in New Zealand if correctly sited.

Key Points

- The site sensitivity of *Paulownia* suggests it will remain a niche species for New Zealand
- *Paulownia* is still a species with potential for specialist markets
- *Paulownia* is an excellent amenity species
- *Paulownia* has potential for agroforestry and for timber production in shelterbelts
- *Paulownia* may develop a market in Australia which could open up opportunities for New Zealand-grown material.

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