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Paulowmia as a novel biomass crop for Northern Ireland?

A review of current knowledge

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1 Summary

This report provides a detailed review of the literature on *Paulownia* research across the world. The main objective of this report was to assess the potential of *Paulownia* as a novel biomass crop for Northern Ireland, based on previous work in this area. *Paulownia* trees originate from China and are also grown throughout Asia, USA, Australia and Europe. Although a number of *Paulownia* species exist, only the ornamental species *Paulownia tomentosa* is currently grown in the UK. With optimal conditions in terms of light and moisture, *Paulownia* is reported to be one of the fastest growing trees in the world. The trees can be damaged by frost and require a sheltered place for growth.

Paulownia timber has many uses, including timber for construction, doors, furniture, kitchens etc. The deep rooting system of *Paulownia* in combination with the rapid rate of growth enables it to take up more nutrients than other species and may therefore offer potential for bioremediation purposes. *Paulownia* leaves can be used for animal feed and honey is made from the bright colourful flowers in China.

Intercropping with wheat is common practice in China, where it is important to utilise the ground for food production in addition to lumber purposes. There is little competition for nutrients between *Paulownia* and wheat in an intercropping system, whereas the converse applies to *Paulownia*-maize intercropping. Recent studies have acknowledged the possibility of *Paulownia*-switch grass intercropping, both being renewable energy resources.

Because of the high cellulose content of *Paulownia*, cellulosic ethanol can be produced as a renewable energy fuel. Cellulosic ethanol is reported to have much reduced greenhouse gas emissions when compared to ethanol produced via a sugar/starch-based fermentation.

Interest in *Paulownia* is gaining momentum around the world, due to its fast growing nature, the ability to take up nutrients and the potential for intercropping. Along with this, *Paulownia* may offer the possibility of producing home-grown timber, reducing the requirement for importation of timber into the UK, which is common practice. Considering that the majority of woody biomass in Northern Ireland comes from the growing of willow, *Paulownia* may also offer potential as a novel source of biomass in Northern Ireland. The fast-drying nature of the wood by natural methods (air drying) is interesting, considering the considerable energy requirements for willow drying. There are currently no *Paulownia* trees growing in Northern Ireland and they may offer potential for biomass and bioremediation purposes. It may also be worthwhile examining the potential of the leaves for fodder purposes.

2 Introduction

Image courtesy of Mr. Nigel Young
World Paulownia Europe Ltd.
(Image on front cover also)

2.1 What is *Paulownia*?

2.1.1 Taxonomy

Paulownia is a tree with a genus of between 6–17 species (depending on the taxonomic authority) from the monogeneric family *Paulowniaceae*, related to and sometimes included in the *Scrophulariaceae*. *Paulownia* is a genus of Asian hardwood trees native of China and which have been cultivated there for the past 3000 years (Bergmann, 1997). The genus was named in honor of Queen Anna Pavlovna from The Netherlands (1795–1865), daughter of Tsar Paul I of Russia.

2.1.2 Scientific classification

(http://en.wikipedia.org/wiki/Paulownia) (Accessed 5th October, 2007).

Kingdom: *Plantae*
Division: *Magnoliophyta*
Class: *Magnoliopsida*
Order: *Lamiales*
Family: *Paulowniaceae*
Genus *Paulownia*

2.1.3 *Paulownia* species

Commonly known as kiri, at least six species of *Paulownia* are currently recognised. Such species include *P. elongata, P. fargesii, P. fortunei, P. galbrata, P. taiwaniana* and *P. tomentosa* (El-Showk and El-Showk, 2003). Others report 6-17 species of *Paulownia* including *P. catalpifolia* and *P. kawakamii* (http://en.wikipedia.org/wiki/Paulownia) (Accessed 5th October, 2007).

2.2 History of *Paulownia* cultivation

Paulownia is a tree with the C_4 photosynthetic pathway that increases the rate of leaf sugar production in warm conditions. Most species of plant use the C_3 photosynthetic pathway, which fixes CO_2 from the atmosphere using the Rubisco enzyme. The C_3 cycle uses the fixed CO_2 and energy from sunlight to make sugars but the process is inefficient because the enzyme Rubisco is not saturated and not very specific, meaning that it also fixes atmospheric oxygen. This inefficiency increases at high temperatures and low CO_2 concentrations. Conversely, C_4 plants can overcome the inefficiency of C_3 photosynthesis and C_4 plants therefore have the photosynthetic edge over their C_3 counterparts when atmospheric CO_2 is low and light and temperature are high.

Paulownia was introduced into the USA in the 1800's where it flourished after the accidental release of *Paulownia* seeds into the wild from packaging material for Chinese dinner wear. Due to its relatively rapid rate of growth *Paulownia* has been described as "the tree of the future" but it is still relatively undeveloped as a crop species. However, over the late 1980's and 1990's *Paulownia* has been attracting more interest (www.paulowniatrees.com.au/History.htm, accessed 20th August, 2007). *Paulownia* and can be propagated by seed, root or stem cuttings and under normal conditions, a 10 year old *Paulownia* tree can reach 30-40 cm in diameter, 10-12 m in height and with a timber volume of 0.2-0.6 m^3. Such growth rates can be exceeded in a good habitat (http://ecoagriculturepartners.org/documents/meetings/Nairobi04/posters/Yang_abstract.pdf, accessed 23rd October, 2007).

2.3 *Paulownia* wood and leaves/flowers

Paulownia wood is used in house construction, for paper pulp, furniture making, farm implements and musical instruments (Ayan *et al*., 2003). The various end uses for *Paulownia* for furniture making are comprehensively described by Ayan *et al*. (2003). These authors stated that the wood is about 40% lighter than ordinary wood and is very promising for pulp and paper. Lyons (1993) reported that *Paulownia* timber air dries readily and has excellent thermal and electrical insulation characteristics. Japanese researchers described some of the properties of particle board made from low quality *P*. *tomentosa* and concluded that low quality *Paulownia* trees offer potential as a raw material for particle board manufacture (Kalaycioglu *et al*., 2005). Lyons (1993) reported that the branches of the tree can be used for household energy and a 10 year old tree has been reported to produce 350-400 kg branches for fuel (Zhaohua, 1987). *Paulownia* is said to require minimal management and little investment (El-Showk and El-Showk, 2003) and has been receiving greater attention as a short-rotation woody crop in recent years (Bergmann *et al*., 1997).

Paulownia also has a range of medicinal properties which are comprehensively described by Ayan *et al*. (2003), and the leaves can be used for animal fodder. In China, after one year's growth when *Paulownia* was cut down, the leaves were offered to pigs and sheep (Zhaohua, 1987). *Paulownia* leaves are reported to have a similar feeding value to lucerne and are suitable for combining with wheat straw or hay for feeding to cattle, sheep or goats (World Paulownia Europe) (http://www.worldpaulownia-eu.com/usesforpaulownia.html) (Accessed 11th October, 2007). World Paulownia Europe state that if trees are planted at 540 trees/ha, *Paulownia* will produce 1220 kg DM/ha with 20% protein and 60% digestibility. A *Paulownia* tree that is 8-10 years old is reported to have 100 kg fresh leaves, with 2.8-3% Nitrogen (N) and 0.4% potash. Data detailing the chemical composition of the *Paulownia* leaf are (%) ash (7.8), protein (22.6), organic matter (91.4), phosphorus (0.6), calcium (2.1), iron (0.6), zinc (0.9), metabolisable energy (MJ/kg) (15-18) (El-Showk and El-Showk, 2003). The potential of the leaves as an ensiled fodder crop for Northern Ireland may warrant investigation, perhaps in mini-silos. When the leaves fall, they can be a valuable source of organic matter and nutrients for the soil (Wang and Shogren, 1992) and can also be used for compost (Lyons, 1993).

2.4 Growing conditions

Paulownia trees are very hardy, can tolerate a range of temperatures and have been reported to grow at altitudes up to 2000 m and latitudes 40^0 N and 40^0 S. The *Paulownia* tree grows 5-6 m tall during the first growing season and adds 3 to 4 cm in diameter annually if optimal growing conditions are present (El-Showk and El-Showk, 2003). However, other reports have suggested that the *Paulownia* grew 4.9 m after 4.5 months growth in Maryland (Preston, 1983). In trials that were conducted under biomass conditions with WPI Georgia and North Carolina State University (NCSU), trees that were cut off at the stump had grown 12-18 feet (3.6-5.5 m) in 16 months, with yields of 84 tonne DM/ha/annum. If we assumed a yield equivalent to one third of this figure for local conditions, then we would predict a yield of 28 tonne DM/ha/annum for Northern Ireland (Personal communication, Mr Nigel Young, World Paulownia Europe Ltd.).

The root system of the *Paulownia* tree is unique, in that the roots grow deep in the earth and its crown develops a loose structure (Ayan *et al*., 2003). Roots have been reported to reach 0.8-1.5 m or even 2 m in length and in sandy and other soils, 76% of the absorbing roots reach a depth of 40-100 cm, with only 12% of the roots within 0-40 cm. In comparison, almost 80% of wheat roots and 95% of maize roots are generally distributed 40 cm into the soil (http://ecoagriculturepartners.org/documents/meetings/Nairobi04/posters/Yang_abstract.pdf) (Accessed 23rd October, 2007). Root development is dependant on soil structure, where *Paulownia* thrives in a loose, well drained sandy soil. Details on the growing process of *Paulownia* are located at http://www.paulowniatrees.com.au/Photo.htm (Accessed 5th October, 2007).

2.5 *Paulownia* management-biomass

A *Paulownia* plantation can be harvested on a number of occasions, giving a continuous source of wood. *Paulownia* trees need to be coppiced, pruned and thinned, with trees that have had the first years growth being cut to encourage coppicing giving better formed stems (www.private forestry.org.au/paul.htm) (Accessed 20th August, 2007). The trees are pruned in the second and third year to a height of 4-6 m to provide a butt log that is free of knots. Thinning of the trees may also be required but is dependant on the initial planting density. World Paulownia Europe reported that having established the trees (for biomass purposes), they are cut down to the stump after the first year to encourage sprouting. Five or more stems are then allowed to develop, which can be harvested annually with the tree being allowed to grow back each year.

2.6 Planting *Paulownia*

2.6.1 Soil conditions

Whilst *Paulownia* can tolerate a variety of soil conditions, they are adversely affected by water logged soils. Heavy peat or sandy soils are favourable for the growth of *Paulownia*, with the converse applying for clay and rocky soils. The ideal pH of the soil for *Paulownia* is between 5 and 8. It is reported that *Paulownia* will not thrive in soils that are podsolic with heavy clay subsoils (www.private forestry.org.au/paul.htm) (Accessed 20th August, 2007).

Australian researchers (Lyons, 1993) reported that the soil requirements for successful growth of *Paulownia* were:

1. A deep soil with a porosity exceeding 50%, with sandy, volcanic and deep alluvial soils being best. *Paulownia* will also grow on soils that have naturally low humus content and with low fertility, providing drainage is good and trees are fertilised
2. Soil pH between 5-8

2.6.2 Site preparation

Paulownia is generally planted in spring and prefers to have a south facing exposure with some wind protection. As with all trees, young *Paulownia* should be protected from grazing animals which would damage the bark whilst feeding. It is recommended that the planting site should be irrigated to moisten the soil and to reduce labour input. *Paulownia* saplings are reported to require irrigation on the day they are planted and a few days after planting, until they have established a good root system. Summer rainfall/irrigation is also required for *Paulownia* (www.private forestry.org.au/paul.htm) (Accessed 20th August, 2007). Lyons (1993) reported that *Paulownia* trees thrive best in high rainfall areas (800 mm or more) if there is good drainage. This author also reported that rainfall of relatively even distribution is required or irrigation and/or available ground water 1-1.5 m below ground level.

2.6.3 Temperature, light and wind

Optimal temperatures for growth are reported to range from 24-29^{O}C and all species of *Paulownia* growing in Australia have been reported to withstand temperatures ranging from -10^{0}C to +40^{0}C (www.paulownia trees.com.au/History.htm) (Accessed 20th August, 2007). Australian researchers (Lyons, 1993) reported that *Paulownia* grows best in temperatures ranging from 24-30^{0}C but that mature *P. tomentosa* can endure temperatures as low as -20^{0}C. These trees require full light for best growth but *P. fortunei* and *P. fargesii* can tolerate shade to a limited extent as they have been grown in China in such conditions. *Paulownia* trees are not suited to areas with strong winds but thrive well in areas that are sheltered.

2.6.4 Planting *Paulownia*

Australian researchers (Lyons, 1993) reported that the site requirements for successful growth of *Paulownia* were:

1. A sloping and effectively drained site
2. A site with no frost hollows and with sufficient air drainage as heavy frosts in spring can damage the stems of young trees and kill new growth
3. A sheltered site, which is especially important when the trees are young

2.6.4.1 Paulownia for forestry

When planting *Paulownia*, it is reported that holes should be dug 2 to 3 feet deep and at least 4 feet in diameter (http://www.fast-growing-trees.com/Instructions/EmpressInst.htm) (Accessed 25th October, 2007). It is important to control weeds before establishment of the trees and weed control should generally continue for 3-5 years, when canopy closure is established (www.private forestry.org.au/paul.htm (Accessed 20th August, 2007).

2.6.4.2 Paulownia for biomass

World Paulownia Europe reported that for the efficient production of biomass, *Paulownia* trees are planted at a higher density than that required for timber production (1960 and 750/ha respectively) (http://www.worldpaulownia-eu.com/faqs.html) (Accessed 23rd October, 2007). The recommended planting density for *P. elongata* for biomass purposes is 1680 trees/ha, with an 8'X8' spacing (Personal communication, Mr Nigel Young, World Paulownia Europe Ltd.), such figures being based on several years of commercial trials. Mr Young also reported that the planting density should match the harvesting machinery to be used.

2.6.5 *Paulownia* - Stages of development

(Images courtesy of Mr. Nigel Young, World Paulownia Europe Ltd.)

Kurdistan *Paulownia* seedling in April after planting in March

Kurdistan *Paulownia* seedling in May

Kurdistan *Paulownia* seedling in June

Kurdistan *Paulownia* seedling in July

Kurdistan *Paulownia* seedling in September

Kurdistan *Paulownia* in November

***Paulownia elongata* cut for biomass with 16 months regrowth**

3 *Paulownia* Research

Image courtesy of Mr. Nigel Young
World Paulownia Europe Ltd.

3.1 China

3.1.1 Intercropping/AgroForestry

The Chinese are presently intercropping with *Paulownia* on some 1.3 million ha of land throughout the country. If a field will be planted with another crop, for example wheat, it is recommended that the planting density should be no more than 500 trees/ha, perhaps being as low as 300 trees/ha at 3 m x 6 m (Figure 1). The hole size should be 70-80 cm on each side and 50-60 cm deep. After the trees are planted, 15-20 cm soil should be placed around the saplings, with the sapling being at least one year old with an established root system. In a study by Chinese researchers to examine the energy balance and economic benefits of two agroforestry systems (*Paulownia* intercropping system and tea intercropping system in the south) in north and south China (Jianbo, 2006), it was concluded that intercropping in agroforestry systems has the potential to increase energy flow. Hou (1988) reported an output of some 2 million m^3 *Paulownia* in China in 1987, with an expected increase to over 10 million m^3 by the mid 1990's.

Wang and Shogren (1992) examined that development of intercropping with *Paulownia* in China (Table 1) and the impact of government policy on its development in China. When *Paulownia* is intercropped with wheat, the stages of growth of the two plants are very different. While winter wheat is growing from a seedling to reach a tillering stage, *Paulownia* trees have a period of rest, meaning that there is no major competition for water and other nutrients (Wang and Shogren, 1992). During the last month before the wheat is harvested, *Paulownia* can have a negative effect on wheat growth by limiting the amount of light that the wheat can get due to the canopy of the *Paulownia* tree. Zhao *et al*. (1986) reported that the yield reduction under the canopy of the *Paulownia* tree was more than offset by gains from areas that were not growing under the canopy when 7 year old *Paulownia* growing at a density of 60/ha were examined (Table 2).

Figure 1 *Paulownia*-wheat intercropping in China

http://forestry.msu.edu/China/2006/Presentations/Jake.pdf

(Accessed 5th October, 2007)

By kind permission of Mr. Jacob Baker, Michigan State University

Table 1 Area of land intercropped with *Paulownia* in the major provinces in China

Province	Area (‘000 ha)	% Total arable land
Henan	1718.7	24.6
Shandong	863.3	12.5
Hebei	162.0	2.5
Anhui	139.3	3.2
Shaanxi	80.0	2.3
Shanxi	22.7	0.6
Jiangsu	20.0	0.4

(Source: China’s Forestry yearbook of 1949-1986)

Table 2 Yield of wheat in intercropping systems with *Paulownia* trees

System	Wheat yield (kg/ha)	Weight/1000 grains (g)	Timber volume	
			m^3/tree	m^3/ha
Wheat	2113.5	36.2		
Wheat-*Paulownia*				
Under canopy (20% area)	1567.5	34.3		
Not under canopy (80% area)	2706.0	38.1		
Mean	2478.3	37.3	0.15	9.2

(Zhao *et al*., 1986)

Researchers have suggested that *Paulownia* trees significantly enhance the microclimate for growing crops due to their extensive root system (Wang and Shogren, 1992). Earlier researchers reported that *Paulownia* trees that were grown in the western Henan Province of China reduced the speed of wind by 45-50%, increased the relative humidity by 5-17%, reduced water evaporation by 15-30% and increased water content in a tillage layer by 5-15% (Wei, 1986).

Borough (1991) provided details on the growth of *Paulownia* trees in China (Table 3)

Table 3 Growth of some better grown *Paulownia* trees in China

Species	Age (Years)	DBH (cm)	Height (m)	Volume (m^3)
P. elongata	19	104	17.1	4.8
P. elongata	13	73	17.5	2.5
P. fortunei	75	134	44.0	22.5
P. fortunei	31	101	21.7	6.7
P. fortunei	11	75	22.0	3.7
P. fortunei	80	202	49.5	34.0

(Borough, 1991)

3.1.2 Economics of intercropping

Data presented in a paper by Wang and Shogren (1992) to examine the production costs and net revenues of a wheat-only system compared with a wheat-*Paulownia* system are given in Table 4. In this table, annual wheat production is used for both systems, with *Paulownia* cost being the average of 7 years. The net expected revenue of *Paulownia* timber was calculated using the timber volume data in Table 4 and its market price. No account is taken for the value of *Paulownia* leaves and branches and no depreciation factor was used in calculations.

Table 4 Net revenues of wheat and wheat-*Paulownia* systems in Henan, China[1]

System	**Revenue** Yuan/ha/year	**Cost** Yuan/ha/year	**Net revenue** Yuan/ha/year
Wheat	625.60 (41.22)[2]	465.00 (30.64)[2]	160.60 (10.58)[2]
Wheat-*Paulownia*			
Wheat	723.66 (47.68)[2]	465.00 (30.64)[2]	258.66 (17.04)[2]
Paulownia	337.68 (22.25)[2]	13.71 (0.90)[2]	323.97 (21.35)[2]
Total	**1061.34 (69.93)**[2]	**478.71 (31.54)**[2]	**582.63 (38.39)**[2]

[1] Zhao *et al*. (1986); [2] £/ha/year; 1 Chinese Yuan = £0.0659 (28th August, 2007)

More recent research by Fu-Xu and Ping (2003) who examined *Paulownia*-crops intercropping over the past 20 years concluded that the intercropping system increased the quality and yield of crops and increased the *Paulownia* volume and economic benefit. These authors suggested that a number of areas require further research, including the mechanism of production variation with the intercropping system, intercepting of sunlight by *Paulownia* and its effect on crop production, the development of indexes to estimate the economic and social benefits of the crop-*Paulownia* system, the impact of secretions from the *Paulownia* roots on crop production and the effect of intercropping on the agri-ecological system.

Other *Paulownia* intercropping studies in Eastern China with maize or beans or ginger demonstrated that maize and beans suffered whilst growing as intercrops, with a reduction in yield of 63% and 68% respectively, compared with sole crops while ginger yields increased by 134% when intercropped with *Paulownia* (Newman *et al*., 1998).

If agricultural production from the land is the main objective in a crop-*Paulownia* system, the optimum intercropping pattern is given as trees to be spaced no closer than 5 X 20 m for the first 6-7 years, after which trees should be thinned to a spacing of 5 X 40 m, with new rows of trees being planted to replace those in thinned rows. After the new trees reach 4-5 years, the remaining trees aged 10-11 years could be harvested (Zhaohua, 1987).

3.1.3 Government policy in China

Government policy has had a significant impact on the development of agroforestry in China, with a number of incentives having a positive impact on the development of the crop-*Paulownia* system (Wang and Shogren, 1992). A requirement for environmental conservation and timber production in China were the two main areas that stimulated the formation of policy. However, as food production is a high priority in China, it was imperative that agroforestry systems did not negatively impact on the land available for food production, giving the opportunity for intercropping. There are government subsidies for purchasing *Paulownia* saplings in many areas of China, reducing the cost of initiating the system. In addition to this, the government have supported extension programs to provide training classes and technical advice on growing *Paulownia*. Wang and Shogren (1992) reported that the successful performance of the crop-*Paulownia* system in China is likely to make this intercropping system an attractive option for other countries.

3.2 USA

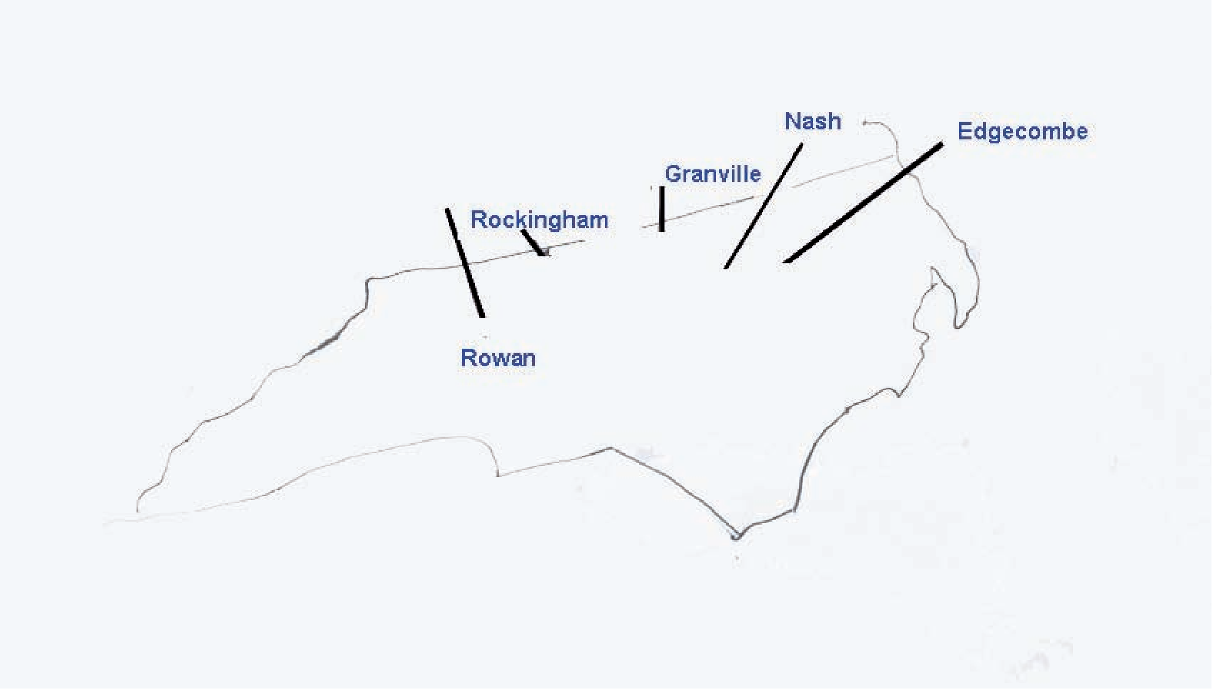
3.2.1 Ovens Research Station

A report by Lyons (1993) described agroforestry research trials at the Ovens Research Station, where *P*. *fortunei* grew very fast under irrigation on river flats and tree diameter exceeded 17 cm for trees that were 2 years old and transplanted out of a nursery when they were 6 month old poles. This author also reported that in comparable areas of China and Japan and on good sites, the trees could reach 22 cm DBH and be 10 m tall, with a clear bole of 5 m in 4 years. Lyons (1993) reported that it is usual to see a diameter of 40-50 cm in 10 years, with production rates of 12 m^3/ha/year.

3.2.2 North Carolina

There are limited data available regarding the growth potential of *Paulownia* species for other areas in the United States. Bergmann (2003) reported that a few field trials were conducted in Texas (Dong and Van Buijtenen, 1994) and North Carolina (Mahalovich, unpublished). Bergmann (2003) reported on the survival and growth potential for *Paulownia elongata*, *Paulownia fortunei* and *Paulownia* X “Henan 1” (a hybrid cross between *elongata* and *fortunei*) in North Carolina. Having established *Paulownia* field trials at four sites in North Carolina in 1996 and at a further site in 1998, the main aim of the study was to establish the survival and growth potential in the field. *Paulownia* was either grown from seed, propagated through rooting stem cuttings from greenhouse stock plants or from rooting micro shoots from tissue culture. All plants were grown to 10 cm in the greenhouse before being moved outdoors for 2-3 weeks to acclimatise prior to planting. A description of the sites used for field trials is given in Figure 2.

Figure 2 Sites of establishment of *Paulownia* in North Carolina



3.2.2.1 Field establishment (North Carolina Trial)

In this trial, existing field vegetation was killed off 2 weeks prior to planting using glyphosphate along strips that were 1 m wide. Plants ranging between 15-30 cm were then planted after exposing the soil to a depth of 30 cm down the middle of rows. A spacing of 4.3 m X 4.3 m was used at all five sites and 8 litres of water was applied to each tree post-planting if the soil was dry. Trees were subsequently watered for four weeks if at least 2.5 cm rain did not fall each week.

3.2.2.2 Field maintenance (North Carolina Trial)

For the first growing season, an area of 1 m (diameter) was kept free of weeds whereas the remaining area was mowed to reduce the incidence of weeds. *Paulownia* trees were maintained as single stems and were allowed to form branches. In the winter following the first growing season, the trees were cut to ground level. *Paulownia* trees are generally coppiced after the first growing season to allow one to select a single straight stem from numerous stump sprouts that appear at the beginning of the second season. Maintenance (weed control) during the second growing season followed the same pattern as in the first growing season in addition to the removal of auxiliary breaks from trees to eliminate branching. From the third year onwards, any shoots that emerged from the trunk of the tree was removed so that the trees were free of branches to a height of 5 m, with the area under the tree being mowed periodically.

3.2.2.3 Data measurements (North Carolina Trial)

Each year, the diameter breast height (DBH) of the trees was measured (to the nearest 0.1 cm), the height of the trees was measured during the first and second years (to the nearest 0.01 m) and the branch-free bole height was measured in years four and five. Site specific treatments at each of the five sites and results obtained are given in Tables 5 and 6 respectively.

Table 5 Site specific treatments at five sites in NCSU Trial

Site Name	Detail
Rowan County	**Year 1:** *P. elongata* clone plus dairy cow waste and poultry litter to achieve an application equivalent to 21 and 48 kg plant available Nitrogen (PAN)/ha respectively. **Years 2-5:** *P. elongata* plus animal waste applied as a row side dressing to achieve PAN of ~200 kg/ha/year - single application of poultry litter in May or June or applications of cow waste once/month in May, June and August. **Control treatment**-No animal waste
Rockingham County	*P. elongata*, *P. fortunei*, *P.* X “Henan 1” produced through tissue culture and fertilised with ammonium nitrate at 75 kg N/ha in mid July each year
Edgecomb County	*P. elongata*, *P. fortunei*, *P.* X “Henan 1”. Half of trees were seed propagated and half produced by tissue culture. Lagoon effluent sprayed over treatment area 4 times/year to achieve 200 kg PAN/ha/year. An equal area was kept as a water control.
Nash County	*P. elongata, P. fortunei, P.* X “Henan 1”. Three propagation methods used - seed rooted stem cuttings or rooted micro shoots produced through tissue culture. All clones were established by tissue culture. Trees fertilised with 75 kg N/ha via ammonium nitrate application in mid July.
Granville County	*P. elongata* clone plus 50 or 150 kg N/ha/year. Fertiliser applied as 10-10-10 N-P-K in early June each year to give 50 kg N /ha to the entire test site, followed by ammonium nitrate (34-0-0) in mid July and mid August each year to give an additional 50 kg N/ha each time to the plots with a higher N application.

Table 6 Results from site specific treatments at five sites in NCSU Trial

Site Name	Detail
Rowan County	100% tree survival and excellent growth. Mean DBH was 23 cm with a branch-free bole of 5.7 m at 5.4 years old. Animal waste application influenced DBH of trees at 1.1, 2.1 and 5.4 years old but had no effect on tree height or branch-free height at any age. The DBH was greater with poultry litter application than a water control at age 5.4. See Table 7 for full details.
Rockingham County	85% tree survival. Trees propagated via seed accounted for the majority of dead trees. 95% survival for vegetatively propagated trees. No difference in DBH between *P. elongata* and *P. fortunei* at age 5.4 but *P*. X “Henan 1” had a smaller DBH than the two species at the same age.
Edgecomb County	57% tree survival across species and swine lagoon treatments at age 5.4. For seed propagated trees, survival was significantly different among species (P<0.01), being greater for *P. elongata* (70%) than *P. fortunei* (36%) and *P*. X “Henan 1” (38%), with no significant difference between *P. fortunei* and *P*. X “Henan 1”. Survival was greater for trees of the same species that were vegetatively propagated than those that were propagated by seed. Swine lagoon effluent had a significant effect after the first year only (P<0.01) and trees that received swine waste were taller.
Nash County	Tree survival was 73% at age 5.4. Seedling survival was greater (P<0.01) for *P. elongata* (88%) than for *P. fortunei* (38%) and *P*. “Henan 1” (25%). Tree survival produced via rooted shoot cuttings was 92%, with no difference among species. Overall, seed propagated trees were inferior to their rooted cutting counterparts within the same species.
Granville County	At age 3.2, survival was 73% across clones and N application rates. Some trees were broken by Hurricane Floyd. The height (P=0.01) and DBH (P=0.03) was influenced by N application rate at age 2.1 but not ages 1.1 or 3.2. Table 8 demonstrates heights and DBH means for the twelve *P. elongata* clones and N applications of 50 and 150 kg/ha/year at this site.

Data detailing the effect of clone type along with animal waste application or N application to *Paulownia* are given in Tables 7 and 8 respectively.

Table 7 Effect of animal waste application (dairy cow waste, poultry litter or none) or clone on the height and DBH of *Paulownia elongata* grown at Site 1 (Rowan County, North Carolina) (mean values)

	Age 2.1		**Age 5.4**	
Treatment	**Height (m)**	**DBH (cm)**	**Height (m)**	**DBH (cm)**
Waste				
Dairy cow	3.9[b]	6.5[b]	5.7[a]	22.9[ab]
Poultry litter	4.5[a]	8.0[a]	5.6[a]	24.7[a]
None	4.5[a]	7.4[ab]	5.8[a]	21.7[b]
Clone				
1	4.7[ab]	7.9[a]	5.9[ab]	25.2[a]
2	4.7[a]	8.0[a]	6.0[ab]	25.6[a]
4	3.5[b]	5.6[bc]	5.4[bc]	15.3[b]
6	4.0[ab]	8.1[a]	6.0[ab]	24.4[a]
8	4.5[ab]	7.4[ab]	6.0[ab]	24.0[a]
9	4.6[ab]	7.9[a]	5.8[ab]	25.6[a]
10	4.1[ab]	7.4[ab]	5.7[ab]	24.9[a]
11	4.0[ab]	6.6[abc]	5.9[ab]	24.4[a]
12	4.6[ab]	8.1[a]	6.1[a]	25.5[a]
17	3.9[ab]	4.9[c]	4.7[d]	12.0[b]
39	4.4[ab]	8.2[a]	5.1[cd]	23.9[a]
64	4.8[a]	7.6[ab]	5.8[ab]	26.5[a]

Ages 2.1 and 5.4 indicate 1 year old stems on 2 year old roots and 4 year old stems on 5 year old roots respectively. Values within a trait and treatment group followed by the same letter are not different at the 0.05 level according to Duncan's critical range test.

Table 8 Effect of N application rate (50 or 150 kg/ha/year) and clone on height and DBH of *Paulownia elongata* grown at Site V (Granville County, North Carolina) (mean values)

	Age 2.1		Age 3.2	
Treatment	**Height (m)**	**DBH (cm)**	**Branch free Height (m)**	**DBH (cm)**
N application (kg/ha/year)				
50	5.1[b]	8.5[b]	4.9[a]	16.1[a]
150	5.3[a]	8.9[a]	4.6[a]	16.4[a]
Clone				
1	5.4[a]	9.4[a]	4.4[bc]	16.5[ab]
2	5.1[a]	8.8[abc]	4.9[abc]	15.2[ab]
3	5.2[a]	8.8[abc]	4.7[abc]	16.3[ab]
4	5.5[a]	8.8[abc]	5.0[ab]	18.0[a]
5	5.3[a]	9.1[ab]	4.4[bc]	16.2[ab]
6	5.1[a]	8.9[abc]	5.4[a]	17.6[ab]
7	5.4[a]	9.0[ab]	5.1[ab]	17.6[ab]
13	5.4[a]	8.1[bc]	4.1[c]	14.3[b]
14	5.3[a]	8.0[c]	4.7[abc]	16.1[ab]
15	5.2[a]	8.3[bc]	4.6[abc]	16.9[ab]
16	4.7[a]	8.5[abc]	4.4[bc]	14.4[b]
17	4.8[a]	8.8[abc]	5.1[ab]	15.6[ab]

Ages 2.1 and 3.2 indicate 1 year old stems on 2 year old roots and 2 year old stems on 3 year old roots respectively. Values within a trait and treatment group followed by the same letter are not different at the 0.05 level according to Duncan's critical range test.

These data from the NCSU trial demonstrate that tree survival was lowest for trees that were propagated by seed in comparison to trees that were propagated by tissue culture. The authors concluded that the application of animal waste or different N application rates as an inorganic fertiliser did not have a pronounced effect on tree survival and growth. For example, the application of dairy cow waste or poultry litter had little effect on the height or DBH of trees aged 2.1 or 5.4 whereas clone type had a more pronounced effect on the height and DBH of trees aged 5.4 when compared to trees aged 2.1. The DBH of the older trees ranged from 12.0-26.5 with different clones ($P<0.05$), with respective values of 4.9-8.1 for trees aged 2.1 ($P<0.05$). Clone type had no significant effect on the height of trees aged 2.1 that received different N application rates but height ranged from 4.1-5.4 m for trees aged 3.2 ($P<0.05$). The DBH of trees aged 2.1 ranged from 8.0-9.1 with different clones ($P<0.05$), with respective vales of 14.4-18.0 for trees aged 3.2 ($P<0.05$).

3.2.3 World Paulownia Institute (WPI)/World Paulownia Europe Ltd.

The WPI in Lenox, Georgia, USA (http://www.worldpaulownia.com/) (Accessed 5th September, 2007) produce *Paulownia elongata* as tissue cultures and these are shipped to the UK for growing on to seedling stage. World Paulownia Europe Ltd. (www.worldpaulownia-eu.com) in Dorset is the UK grower, who also has additional growers in Spain. The *Paulownia elongata* variety is primarily used for forestry plantations and other varieties such as *Paulownia catalpifolia* and *Paulownia tomentosa* are also attainable.

3.3 Australia

3.3.1 Powton Project and Kiri Park Project

"Kiri Park" is located in Western Australia, a property with over 500 hectares of which over 200 hectares is suitable for *Paulownia* plantations (Figure 3). Approximately 150,000 *Paulownia* trees have already been successfully planted, managed and maintained in Kiri Park and the plantation is considered to be one of the leading *Paulownia* plantations in Australia. Figure 4 demonstrates *Paulownia* grown for timber use.

Figure 3 *Paulownia* plantation in autumn at Kiri Park, Western Australia

http://www.effgroup.com.au/kiriphoto.html

(Accessed 5th October, 2007)

By kind permission of Wade Baggott, EFF Group of Companies

Figure 4 *Paulownia* timber (Kiri Park, Western Australia)

http://www.effgroup.com.au/paulowniaphoto.html

(Accessed 5th October, 2007)

By kind permission of Wade Baggott, EFF Group of Companies

3.4 Africa

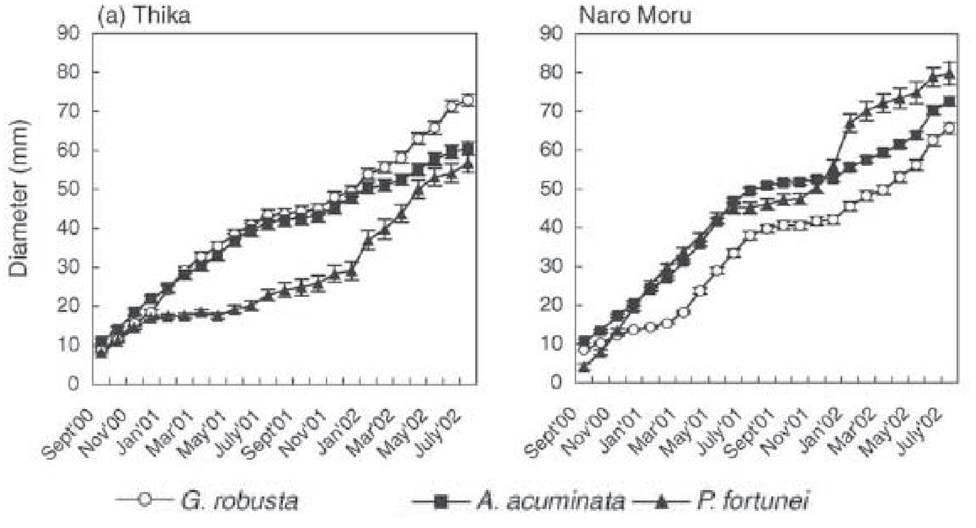
3.4.1 World Agroforestry Centre, Kenya

Professor Colin Black, University of Nottingham collaborated on a project with the World Agroforestry Centre in Kenya, where the hypothesis that deciduous trees (*Paulownia fortunei)* and semi-deciduous trees (*Alnus acuminate)* (Alder tree) were less competitive with crops (maize) than evergreen species (*Grevillea robusta*) (commonly known as the silk oak) (Muthuri *et al*., 2005) was tested (Figure 5). The authors concluded that *P. fortunei* was suited to semi-arid areas and that yield reductions were negligible adjacent to *P. fortunei*, when compared to that of maize adjacent to *G. robusta*, where yield was reduced by 36% (Figures 6-8).

Figure 5 *Paulownia*-maize intercropping in Kenya

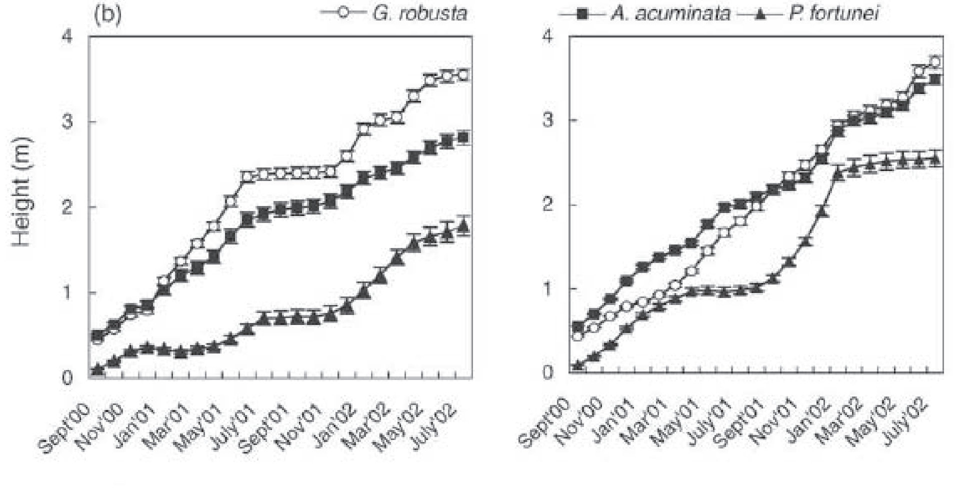
Image courtesy of Professor Colin Black, University of Nottingham

Figure 6 Mean basal trunk diameter of *G. robusta*, *A. acuminata* and *P. fortunei* at two sites in Kenya (Thika and NaroMoru)



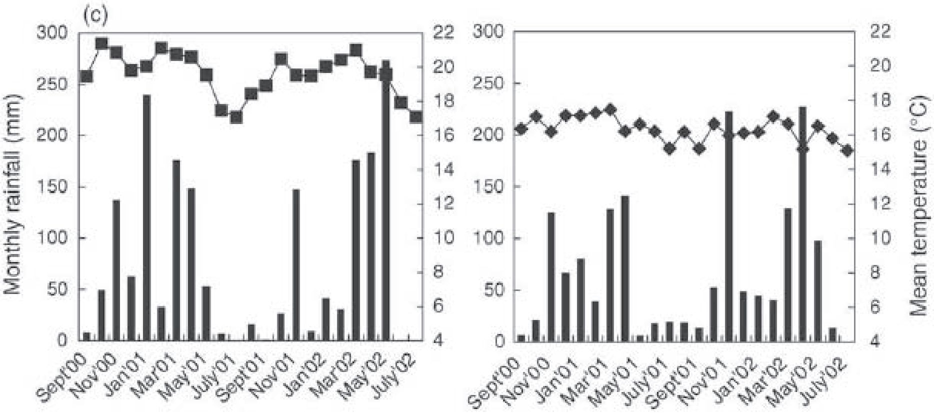
(Muthuri *et al*., 2005)

Figure 7 Mean tree height of *G. robusta*, *A. acuminata* and *P. fortunei* at two sites in Kenya (Thika and NaroMoru)



(Muthuri *et al*., 2005)

Figure 8 Mean daily air temperature and monthly rainfall at two sites in Kenya (Thika and NaroMoru)



(Muthuri *et al*., 2005)

3.5 Bulgaria
"The Spanish company Ferry Group is to invest €42/US$55.2 million in a 3 year project for the production of biomass fuel pellets in Bulgaria near the city of Tran Dnevnik - Feb. 20, 2007". (http://biopact.com/2007/03/bleak-future-for-coal-unless-ccs.html) (Accessed 12th October, 2007).

On the European Commission website, Ferry Energy Ltd. is seeking partners for this project. The closing date is 28th December, 2007.

3.5.1 Partner Search Request: *Paulownia* - Green Energy, Bulgaria
"Ferry Energy Ltd. is looking for partners for the project "Green Energy" under the IEE programme. Ferry Energy believes that "Green Energy" has the potential to become one of the large-scale innovative investments in the field of renewable energy sources. Green Energy is an investment of Ferry Energy Ltd. (a subsidiary of the Spanish holding Ferry Group), encouraged by the Government of Valencian Region and is included in a special Action Plan, published by the European Commission. The investment is the first of its kind in Bulgaria and is broadly supported by renewable energy experts. In 2007, the project received from InvestBulgaria Agency a 1st-class certificate for Green Energy investment. The project includes growing trees for biomass production and processing vegetal by-products for receiving ecological fuel to be used in thermo power plants. The manufacturing activity will be organised in the region of the town of Trun; some other regions have been currently explored too. Fast-growing trees of the *Paulownia* genus, suitable for biomass production, will be grown"

3.6 United Kingdom
3.6.1 Kew Gardens
Several varieties of *Paulownia* are grown at Kew Gardens, namely *P. coreana*, *P. fargesii, P. kawakami*, *P. taiwaniana* and *P. tomentosa*. The trees require good light to grow and are susceptible to wind. The trees are planted from seed in Kew. All scientific collections of *Paulownia* in Kew are for taxonomic research purposes. The

trees only receive water that falls naturally and are not irrigated. The trees have grown to ~20 m in 10 years and receive no fertilizer, only organic mulch (Personal Communication, Mr Tony Kirhman).

3.6.2 University of Reading

There are currently four *Paulownia* trees growing at the University of Reading for ornamental purposes (Figure 9).

Figure 9 *Paulownia tomentosa* growing at the University of Reading

Image courtesy of Mr. Rupert Taylor, University of Reading

4 *Paulownia* for remediation

Image by kind permission of Mr. Jacob Baker, MSU

Research to examine the ability of *Paulownia* to take up nitrates, heavy metals and land contaminants has been conducted over the past two decades (www.worldpaulownia.com/html/remediation.html) (Accessed 20th August, 2007). Such trials included animal waste run off, human waste and organic waste from landfills. Recent work by Zhang *et al*. (2007) in China, where land near a Pb/Zn smelter that was contaminated with heavy metals was revegetated with *P. fortunei* demonstrated that the use of *P. fortunei* for revegetation greatly improved structural and functional characteristics of the soil microorganisms.

In a trial on a military site in the USA, the ability of poplar, willow and *Paulownia* to take up nutrients from contaminated soil was examined and the *Paulownia* was the only one that survived. Pig and poultry farmers in the USA are using the trees to spread manure on as they can utilise a huge amount of nutrients (Personal communication, Nigel Young, World Paulownia Europe Ltd.). World Paulownia Europe reported that "*Paulownia* is an ideal crop for use in areas where large amounts of manures have to be spread".

4.1 Nitrogen uptake

Previous research has demonstrated that *Paulownia* trees that were 8 years old had the ability to remove N at a rate of 930 kg/ha/year, based on an average N foliar content of 2.6% (Zhu, 1991). The World Paulownia Institute describe *Paulownia* as having a "superior uptake of nitrates, heavy metals, contaminants and other elements from shallow and deep sub soil" (http://www.worldpaulownia.com/html/remediation.html) (Accessed 5th September, 2007).

5 Biofuel/Biomass production

Image courtesy of Mr. Nigel Young
World Paulownia Europe Ltd.

Paulownia can be used as an energy source in a number of ways including:

-Burning directly for heat for an individual home or a community heating scheme
-Burning to generate steam for the production of electricity
-A feedstock for pyrolysis to generate gas
-A feedstock for ethanol production using the Brelsford acid hydrolysis process

World Paulownia Europe Ltd. reported on the advantages of *Paulownia* for ethanol production (http://www.worldpaulownia-eu.com/usesforpaulownia.html) (Accessed 11th October, 2007). Such advantages were reported to be:

- Trees do not require annual cultivation, planting, herbicides, pesticides, etc. and can be harvested as required
- Using *Paulownia* for biomass enables rapid production of a harvestable crop (within two years) and continuous production over a number of years without the need for replanting
- Using the Brelsford Dilute Acid Hydrolysis process for ethanol production offers a safe and efficient solution which can use various sources of timber including forest waste and manufacturing off cuts
- The Brelsford process for ethanol production is licensed to the World Ethanol Institute, a sister company of World Paulownia Institute, LLC
- In comparison to cereal crops, the use of *Paulownia* for ethanol production has a higher efficiency in terms of energy in:energy out

Paulownia can be used as a “cellulosic ethanol generator”, where cellulosic ethanol is a blend of ethanol produced from biomass including waste from urban, agricultural and forestry sources. Prestige Plantations in Australia reported that recent studies have shown the *Paulownia* biomass can provide the feedstock for cellulosic ethanol production. Cellulosic ethanol is said to reduce greenhouse gas emissions (GHG) by 85% over reformulated petrol. For comparative purposes, it is interesting to note that sugar-fermented ethanol reduces GHG emissions by 18-29% over petrol (http://prestigeplantations.com/biomass.html) (Accessed 12th October, 2007). This would suggest that ethanol from *Paulownia* is capable of providing an opportunity for carbon credits. The technical specifications of *Paulownia* wood are presented in Table 9 (El-Showk and El-Showk, 2003).

Table 9 Technical specifications of *Paulownia* wood

Density	*(at 10% moisture content)*	17.91
Specific gravity		0.265
Shrinkage coefficient	Specific gravity	0.21-0.27
(green to oven dry)	Radial	1.1-2.0
	Tangential	2.1-3.5
Binding properties	Modulus of rupture	5740
(at 12% moisture)	Modulus of elasticity (x10)	0.838
Chemical composition	Cellulose (%)	46-49
	Hemicellulose Pentozan (%)	22-25
	Lignin (%)	21-23

(El-Showk and El-Showk, 2003)

Prestige Plantations in Australia reported that intercropping with switch grass can increase *Paulownia* yield by 378l ethanol/tonne switch grass. As the switch grass requires N fertiliser post-harvest, this presents a perfect symbiosis as *Paulownia* leaves are N-rich (http://prestigeplantations.com/biomass.html) (Accessed 12th October, 2007).

A recent paper by Cuiping *et al*. (2004) to describe the chemical elemental characteristics of biomass fuels in China provided data on the phoenix tree (*Paulownia catalpifolia*), willow (*Salix*) and poplar (*Populus tomentosa*) (Tables 10 and 11).

Table 10 Proximate analysis of reference fuels

Fuel	Moisture (wt%)	Ash (wt% db)	Volatile matter (%)	Fixed carbon (%)	Calorific value (MJ/kg)
Willow	9.08 ± 1.45	6.17 ± 3.7	69.2 ± 5.08	15.55 ± 1.99	18.79 ± 0.40
Poplar	7.91 ± 1.65	2.63 ± 0.87	74.04 ± 0.36	15.42 ± 1.14	18.57 ± 0.17
Phoenix	7.74	5.28	68.68	18.29	17.96
Coal	2.83 ± 0.66	20.08 ± 3.49	28.33 ± 1.89	49.08 ± 2.12	34

(Cuiping *et al*., 2004)

Table 11 Characteristics of reference fuels-ultimate analysis

Fuel	N	C	S	H	O
Willow	0.77 ± 0.79	46.79 ± 1.14	0.30 ± 0.17	7.10 ± 0.44	40.60 ± 3.75
Poplar	0.17 ± 0.06	47.46 ± 0.45	0.10 ± 0.09	6.74 ± 0.02	44.50 ± 1.36
Phoenix	0.70	48.14	0.04	7.88	39.84
Coal	1.13 ± 0.01	63.78 ± 2.33	0.97 ± 0.19	3.97 ± 0.38	10.08 ± 4.66

(Cuiping *et al*., 2004)

6 Density and drying

Paulownia is a very durable and light wood, weighing 14-19 lb/foot^3 and is almost one third the weight of oak and half the weight of pine. The specific gravity of *Paulownia* ranges between 0.23-0.30 (23-30% of water density). Air-drying of *Paulownia* is reported to take as little as 30 days and boards can be kiln dried to 10-12% moisture at high temperatures in 24 hours without warping. Shrinkage of the wood from green to oven-dry is reported as 2.2% radial and 4% tangential. During changes in humidity, *Paulownia* remains stable and has little shrinkage or expansion in comparison to the majority of other woods (http://prestigeplantations.com/timber.html) (Accessed 12th October, 2007). Olson *et al*. (1989) reported a drying time of 39 days for *Paulownia* timber (from green) to reach 20% moisture content, i.e. 3.5% moisture content loss per day in late May.

7 Carbon sequestration

There are limited details available regarding the carbon sequestration value of *Paulownia*. One ha of *Paulownia* is reported to absorb ~1235 tonne CO_2/year (http://www.neda.gov.ph/Knowledge-Emporium/details.asp?DataID=427) (Accessed 11th October, 2007) and The World Paulownia Institute reported the *Paulownia* tree as being an excellent sequester of CO_2 from the air.

The web page of Winrock Financial Ltd. provides details on the biomass emissions of the Megafolia-Paulownia Tree™ as shown in Table 12 (http://www.mftree.com/emission.html) (Accessed 9th October, 2007).

Table 12 Biomass emissions of the Megafolia tree in comparison to coal and diesel (lb gas/'000 bone dry tonne equivalency)

	Megafolia Tree	Coal	Diesel
Sulfur Oxides	0	3500	555
Nitrous Oxides	0	3100	10,500
Carbon Monoxide	0	960	26,000
Methane	0	15	0
CO_2	375	1100	1550
Other harmful gasses	0	290	5600
Particulate Matter	110	140	180

Winrock International conducted a study to assess the carbon sequestration potential of *Paulownia* plants on a variety of land types in comparison with that of other fast-growing alternatives in 2004, with funding from NRG Energy, Inc. ($16,999), Division: Ecosystem Services (http://www.winrock.org/common/files/2004_global_projects_financial_statement_low_res.pdf) (Accessed 12th October, 2007).

8 Disease

Lyons (1993) reported that little was known regarding potential disease issues for *Paulownia* in Australia but that *Paulownia* grown in China was attacked by many diseases and insects, the most serious being witches broom (Figure 10). Witches Broom is characterised by a clustering of branches and it impairs tree growth and vigour and can lead to premature death. The disease affects the branches of the tree, trunk, flowers and roots (Lyons, 1993).

Figure 10 Witches broom on *Paulownia*

http://forestry.msu.edu/China/2006/Presentations/Jake.pdf

(Accessed 9th October, 2007)

By kind permission of Mr. Jacob Baker, Michigan State University

The tip of infected branches dies and many buds sprout as a result, forming many bunches of twigs. The wood of an infected tree is of poor quality as growth rates are reduced substantially and is then often unfit for commercial use. A solution to the problem has still not been found. Lyons (1993) reported that the disease is not prevalent in Australia and the importation of various clones as tissue cultures has prevented this disease from entering Australia.

Other diseases reported to have occurred in China are Anthracnose (also known as leaf blight, which is a fungal disease) (Figure 11) and *Sphaceloma paulowniae* and mistletoe (*Loranthus* sp.) can also cause some considerable damage (Lyons, 1993). Further information on these diseases can be found at the following web link http://idrinfo.idrc.ca/Archive/Corpdocs/071235/071235j.htm (Accessed 9th October, 2007).

Figure 11 Anthracnose infected leaf

http://www.ipm.ucdavis.edu/PMG/PESTNOTES/pn7420.html

(Accessed 9th October, 2007)

By kind permission of Mr. Jacob Baker, Michigan State University

9 Discussion

The European Union recently launched its Biomass Action Plan to increase the development of biomass energy from wood, waste and agricultural crops. The planting of *Paulownia* for biomass/wood presents a novel option that would comply with this plan. The DARD Forest service has also been working with wood processors to create sustainability in the wood supply chain. One of the strategic objectives of DARD is for the further conversion of farmland to woodland and forest and the agricultural and forestry processing and marketing grant scheme will provide support towards capital expenditure and new equipment to promote innovation and investment in wood and other renewable energy markets, within which *Paulownia* could potentially be included.

If *Paulownia* was considered as a biomass crop for Northern Ireland, its main competitor would be SRC willow. There are over 40 years of data collected from AFBI, Loughgall on SRC willow as a biomass crop whereas there are no existing data on *Paulownia* biomass in Northern Ireland or the UK. If one were to consider a study to examine the feasibility of *Paulownia* for biomass in Northern Ireland and/or its bioremedial capacity, one should compare the cost of growing *Paulownia* with that of willow. As there are limited data available for *Paulownia*, a number of assumptions were required to be made. Data in Table 13 details the cost of growing *Paulownia* at a range of planting densities (600-1800 plants/ha) and a range of costs (£1-5/tree). As the cost of *Paulownia* trees varies with the quantity ordered, a number of prices/tree are presented. The planting density also varies depending on whether the crop is used for biomass or wood, therefore a range of planting densities were included. At the recommended planting rate of 750 and 1680 plants/ha for wood and biomass purposes respectively (Personal communication, Mr Nigel Young, World Paulownia Europe Ltd.), and a cost of £4/tree, the cost of the *Paulownia* tree alone equates to £3000/ha and £6720/ha for wood and biomass purposes respectively (Table 13).

Table 13 Cost of *Paulownia* trees (£/ha) at a range of planting densities

	Planting density (trees/ha)						
Cost/tree (£)	**600**	**750**	**900**	**1200**	**1500**	**1680**	**1800**
1	600	750	900	1200	1500	1680	1800
2	1200	1500	1800	2400	3000	3360	3600
3	1800	2250	2700	3600	4500	5040	5400
4	2400	**3000**	3600	4800	6000	**6720**	7200
5	3000	3750	4500	6000	7500	8400	9000

When the cost of ground preparation, herbicide, ploughing and power harrowing are included, an additional cost of £120/ha is accrued (assumed the same cost as for willow) (Table 14). Mechanical planting by hand at 0.5 ha/person/day equates to a cost of approximately £324 for planting 1 ha of *Paulownia* for biomass and £162 for planting 1 ha of *Paulownia* for wood. Post-plant rolling is not required as when manual planting is used, the trees are firmed in with the foot. The first years growth will be too great to be cut with a finger bar mower and so a strimmer with a saw blade head can be used for this purpose. The cost for cutting back after the first years growth is assumed to be equivalent to that of willow, being £37/ha. Weed and pest control is costed at £85/ha as leather jacket control would not be required with *Paulownia* as it is for willow. The total estimated cost of planting 1 ha of *Paulownia* for wood and biomass is £3404 and £7286 respectively (Table 14). These figures exclude any grants that may be available for a *Paulownia* enterprise.

Table 14 Cost of growing *Paulownia* for wood and biomass in comparison to willow

	***Paulownia* (biomass) (£/ha)**	***Paulownia* (wood) (£/ha)**	**Willow[#] (£/ha)**
Ground preparation, herbicide, plough, power harrow	120*	120*	120
Mechanical planting	324	162	649
Cuttings/trees carriage and cold storage	6720[§§]	3000[§§§]	750[§]
Post-planting rolling plus residual herbicide and leather jacket control	0	0	152
Cut back after first years growth (finger bar mower)	37	37	37
Weed and pest control (including post cut back herbicide and post planting leather jacket control)	85	85	100
Total establishment cost (£)	7286	3404	1808

[§] 15,000 willow cuttings/ha; [§§] 1680 *Paulownia* trees/ha @ £4/tree; [§§§] 750 *Paulownia* trees/ha @ £4/tree; ([#]Dawson, 2007)

These planting costs are four times and two times greater than that of willow respectively, but costs should be spread over a 15 year period as with willow. Furthermore, the yield of *Paulownia* for biomass is expected to reach almost 30 tonne DM/ha according to World Paulownia Europe Ltd., almost three times that of willow. However, caution should be exercised when using this figure as there are no data on the yield of *Paulownia* for UK conditions. Willow production only breaks even or starts to become profitable at a yield of 10 tonne DM/ha and a return of £40/tonne DM (including a £1000/ha planting grant) (Table 15).

Table 15 Gross margin for SRC Willow at a range of yields and returns/tonne DM

Average annual yield	**£/tonne DM**			
(tonne DM/ha)	**30**	**40**	**50**	**60**
6	-100	-51	-2	47
8	-85	-19	46	112
10	-69	13	95	177
12	-54	45	143	241
14	-38	76	174	306

€1 = £0.666 (Dawson, 2007)

The expected return from *Paulownia* at a range of yields and prices/tonne DM is very variable. For comparison purposes, the current price for 1 tonne of willow chips (at 15% moisture) is £60, which equates to £71/tonne of DM. At a yield of 20 tonne DM/ha and price of £71/tonne DM, it would take over 5 years post-establishment to accrue the cost of planting for biomass if there was no grant aid available. If there was grant aid available for *Paulownia* as with willow (£1000/ha), then it would take 4.5 years post-establishment to recover the cost of planting for biomass. The respective period of time required to recover the cost of planting *Paulownia* for wood without and with grant aid would be 2.4 and 1.7 years post-establishment.

As there are no data available regarding the yield of biomass from *Paulownia* in the UK, caution must be taken that assumed yields are realistic, considering the growing conditions in Northern Ireland, in terms of soil status and temperature. Consequently, calculations on the accumulated returns from *Paulownia* for biomass with no grant aid were made over a fifteen year period, based on assumed yields of 15 and 20 tonne DM/ha, with only 75% of the maximum expected yield being achieved in Year 2 and 100% of the expected yield being achieved each year thereafter (Tables 16 and 17 respectively).

Table 16 Accumulated returns from *Paulownia* for biomass over a fifteen year period, assuming a biomass price ranging from £30/tonne DM to £100/tonne DM, establishment costs of £7286/ha (no grant aid), harvesting, storage and transportation costs of £200/ha and a biomass yield of 15 tonne DM/ha, from Year 3 onwards

		Biomass price (£/tonne DM)							
Year	**Yield (tonne DM/ha)**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
1	0	-7286	-7286	-7286	-7286	-7286	-7286	-7286	-7286
2	11.25	-7149	-7036	-6924	-6811	-6699	-6586	-6474	-6361
3	15	-6899	-6636	-6374	-6111	-5849	-5586	-5324	-5061
4	15	-6649	-6236	-5824	-5411	-4999	-4586	-4174	-3761
5	15	-6399	-5836	-5274	-4711	-4149	-3586	-3024	-2461
6	15	-6149	-5436	-4724	-4011	-3299	-2586	-1874	-1161
7	15	-5899	-5036	-4174	-3311	-2449	-1586	-724	139
8	15	-5649	-4636	-3624	-2611	-1599	-586	427	1439
9	15	-5399	-4236	-3074	-1911	-749	414	1577	2739
10	15	-5149	-3836	-2524	-1211	102	1414	2727	4039
11	15	-4899	-3436	-1974	-511	952	2414	3877	5339
12	15	-4649	-3036	-1424	189	1802	3414	5027	6639
13	15	-4399	-2636	-874	889	2652	4414	6177	7939
14	15	-4149	-2236	-324	1589	3502	5414	7327	9239
15	15	-3899	-1836	227	2289	4352	6414	8477	10539
Mean annual return (£/ha/year)		-260	-122	15	153	290	428	565	703
Mean annual return (£/ha/year) with £1000/ha grant aid		-193	-56	82	219	357	494	632	769

Table 17 Accumulated returns from *Paulownia* for biomass over a fifteen year period, assuming a biomass price ranging from £30/tonne DM to £100/tonne DM, establishment costs of £7286/ha (no grant aid), harvesting, storage and transportation costs of £200/ha and a biomass yield of 20 tonne DM/ha, from Year 3 onwards

		Biomass price (£/tonne DM)							
Year	**Yield (tonne DM/ha)**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
1	0	-7286	-7286	-7286	-7286	-7286	-7286	-7286	-7286
2	15	-7036	-6886	-6736	-6586	-6436	-6286	-6136	-5986
3	20	-6636	-6286	-5936	-5586	-5236	-4886	-4536	-4186
4	20	-6236	-5686	-5136	-4586	-4036	-3486	-2936	-2386
5	20	-5836	-5086	-4336	-3586	-2836	-2086	-1336	-586
6	20	-5436	-4486	-3536	-2586	-1636	-686	264	1214
7	20	-5036	-3886	-2736	-1586	-436	714	1864	3014
8	20	-4636	-3286	-1936	-586	764	2114	3464	4814
9	20	-4236	-2686	-1136	414	1964	3514	5064	6614
10	20	-3836	-2086	-336	1414	3164	4914	6664	8414
11	20	-3436	-1486	464	2414	4364	6314	8264	10214
12	20	-3036	-886	1264	3414	5564	7714	9864	12014
13	20	-2636	-286	2064	4414	6764	9114	11464	13814
14	20	-2236	314	2864	5414	7964	10514	13064	15614
15	20	-1836	914	3664	6414	9164	11914	14664	17414
Mean annual return (£/ha/year)		-122	61	244	428	611	794	978	1161
Mean annual return (£/ha/year) with £1000/ha grant aid		-56	128	311	494	678	861	1044	1228

Based on the findings in this report and the total absence of yield data for *Paulownia* as a biomass crop, such gaps in knowledge should be addressed to ascertain if this tree could provide a novel and practical method to assist Northern Ireland in meeting its energy targets. In the short-term, the suitability and usefulness of *Paulownia* for short rotation forestry (single stem) should be examined in Northern Ireland, in addition to its use as a potential alternative to SRC willow (coppiced). Initial baseline data are required regarding the suitability of *Paulownia* as a biomass crop for Northern Ireland before considering it as a feedstock for ethanol generation, but it is likely that the high capital cost of an ethanol plant and the large area of production required to support it would rule out this option in Northern Ireland. The availability of test sites at AFBI Hillsborough, AFBI Loughgall and CAFRE Loughry Campus would provide an ideal opportunity to examine the effect of climatic differences on *Paulownia* suitability for Northern Ireland conditions. The usefulness of *Paulownia* for bioremediation should also be examined as a novel method to assist the industry in complying with European legislation such as the Nitrates Directive and Water Framework Directive. Recent interest in other novel biomass sources such as Eucalyptus and Poplar should be considered when examining *Paulownia*, by establishing robust field trials to compare Eucalyptus, Poplar and *Paulownia* as novel biomass crops.

10 Conclusions

1. *Paulownia is a* C_4 tree species, native to China, which is of considerable interest due to its very rapid growth rate.
2. *Paulownia* can be grown as single stemmed trees planted at low density for timber production or planted at higher density and coppiced for biomass production.
3. Where optimum conditions prevail in terms of light and water, *Paulownia* is one of the world’s fastest growing trees.
4. Although it is currently mainly grown in warmer climatic zones, it is reported that *Paulownia* will also grow successfully in more temperate climates.
5. There are no data from the UK on the growth rate or yield from *Paulownia.*
6. *Paulownia* is mainly grown in China, Japan and the USA, and used for timber production.
7. *Paulownia* biomass can be used for the production of cellulosic ethanol.
8. The leaves and flowers can also be used for pharmaceutical purposes.
9. The leaves of the *Paulownia* tree can be ensiled and offered to cattle and sheep.
10. Much research on *Paulownia* is currently under way in Australia.
11. It appears that *Paulownia tomentosa* is the more commonly grown species for ornamental purposes in the UK and these trees have been growing from Cornwall to Scotland.
12. Most of these *Paulownia tomentosa* trees have been propagated by seed.
13. It is preferable to propagate *Paulownia* via root cuttings as opposed to seed.
14. The apical bud of *Paulownia elongata*, *tomentosa* and *fortunei* is susceptible to frost and measures must be taken to address this.
15. Poplar may be necessary for windbreak on windy sites.
16. *Paulownia* has a unique root system, where roots grow deep into the earth (up to 2 m) and have an absorptive function.

17. *Paulownia* prefers light/loamy soil such as sands, shale or chalk. It does not thrive in clays or waterlogged soils.
18. The practice of intercropping with wheat is common in China and there is little competition for nutrients between the crops.
19. Intercropping with maize can reduce maize yield.
20. It may be possible to intercrop with winter wheat or oilseed rape in the UK.
21. For forestry purposes, canopy closure occurs after 8 years of growth and it is suggested that alternate rows should be harvested every five years as a consequence, leaving an open canopy for intercrops.
22. *Paulownia* is ready for harvest after 10 years in China, with a diameter breast height of 30-40 cm.
23. With lower temperatures in the UK than in China, it is estimated that a 20-30 year rotation may be required.
24. *Paulownia* regenerates after harvesting from the cut stump and is therefore a renewable resource.
25. With its high rate of growth, the tree is reported to be an outstanding sequester of carbon.
26. *Paulownia* plantations have a significant uptake of nitrogen and other minerals and can be utilised for the bio-remediation of nutrient rich wastes.
27. It is thought that it is worthwhile conducting research on *Paulownia* for short rotation forestry and short rotation coppicing under UK conditions and comparing its hardiness and yield data with that of other biomass sources such as Eucalyptus, Poplar and Willow.

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12 Appendices

Appendix 1 - Classification

Kingdom *Plantae* down to species *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud.

Kingdom Plantae -- Plants

Subkingdom Tracheobionta -- Vascular plants

Superdivision Spermatophyta -- Seed plants

Division Magnoliophyta -- Flowering plants

Class Magnoliopsida -- Dicotyledons

Subclass Asteridae

Order Scrophulariales

Family Scrophulariaceae -- Figwort family

Genus *Paulownia* Sieb. & Zucc. -- *Paulownia*

Species *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud. -- Princesstree

Appendix 2 - *Paulownia tomentosa*

(Thunb.) Sieb. & Zucc. ex Steud. Princess tree

(http://plants.usda.gov/java/charProfile?symbol=PATO2PATO2)
(Accessed 9th October, 2007)

Summary

Duration	Perennial
Growth Habit	Tree
U.S. Nativity	Introduced to U.S.

Morphology/Physiology

Active Growth Period	Spring and Summer
Bloat	None
C:N Ratio	High
Coppice Potential	Yes
Fall Conspicuous	Yes
Fire Resistant	No
Flower Colour	Purple
Flower Conspicuous	Yes
Foliage Colour	Green
Foliage Porosity Summer	Dense
Foliage Porosity Winter	Porous
Foliage Texture	Coarse
Fruit/Seed Colour	Brown
Fruit/Seed Conspicuous	Yes
Growth Form	Single Crown
Growth Rate	Rapid
Height at 20 Years, Maximum (feet)	60
Height, Mature (feet)	70
Known Allelopath	No
Leaf Retention	No
Lifespan	Moderate
Low Growing Grass	No
Resprout Ability	Yes

Shape and Orientation	Irregular
Toxicity	None

Growth Requirements

Adapted to Coarse Textured Soils	Yes
Adapted to Fine Textured Soils	No
Adapted to Medium Textured Soils	Yes
Anaerobic Tolerance	None
CaCO3 Tolerance	Low
Cold Stratification Required	No
Drought Tolerance	Medium
Fertility Requirement	Medium
Frost Free Days, Minimum	180
Hedge Tolerance	None
Moisture Use	Medium
pH, Minimum	4.5
pH, Maximum	7.5
Planting Density per Acre, Minimum	400
Planting Density per Acre, Maximum	800
Precipitation, Minimum	30
Precipitation, Maximum	55
Root Depth, Minimum (inches)	36
Salinity Tolerance	None
Shade Tolerance	Intolerant
Temperature, Minimum (°F)	-8

Reproduction

Bloom Period	Mid Spring
Commercial Availability	Routinely Available
Fruit/Seed Abundance	Low
Fruit/Seed Period Begin	Summer
Fruit/Seed Period End	Fall
Fruit/Seed Persistence	Yes
Propagated by Bare Root	Yes

Propagated by Bulb	No
Propagated by Container	Yes
Propagated by Corm	No
Propagated by Cuttings	Yes
Propagated by Seed	Yes
Propagated by Sod	No
Propagated by Sprigs	No
Propagated by Tubers	No
Seed per Pound	2820000
Seed Spread Rate	Slow
Seedling Vigor	High
Small Grain	No
Vegetative Spread Rate	None

Suitability/Use

Berry/Nut/Seed Product	No
Christmas Tree Product	No
Fodder Product	No
Fuel wood Product	Medium
Lumber Product	Yes
Naval Store Product	Yes
Nursery Stock Product	Yes
Palatable Human	No
Post Product	No
Pulpwood Product	No
Veneer Product	No

Appendix 3 - Site selection and cultivation (World Paulownia Europe Ltd.)

When selecting your site, the main conditions to be taken into consideration are that *Paulownia* will not tolerate wet sites, land with a high water table, or tolerate frost conditions below -20° C.

Ideally, the water table should be at least 1.5 metres or more below the surface. The site should be well drained and slightly sloping.

Soil Types
Clay loam to sandy loam. Beware of untreated heavy clay soils as they prevent drainage and impede root growth.

Rainfall
Generally, 30 to 50 inches annually. Ideally this rainfall should be during the summer which is the main growing season for *Paulownia*.

pH Level
6.5 to 7.5 is ideal. *Paulownia* can grow quite satisfactorily in soils as low as 5.0 but for optimum growth this is not advisable.

Topography
For heavier soils, gently rolling hills of at least 10 degrees are preferable to ensure adequate drainage. For lighter soils, the ground can be flat but the water table must be at least 1.5 meters deep during the wet season to ensure adequate aeration of roots.

Windbreaks
Desirable for the young *Paulownia* due to their extremely large leaves which are susceptible to wind damage.

Pests
Tree guards or fencing of the young *Paulownia* is a must as the leaves of *Paulownia* are very palatable to both domestic stock and wildlife.

Water Supply
In areas where the natural rainfall is low and also during the first two years of growth, irrigation is important.

Temperature
Paulownia can adapt to a wide range of temperatures. The absolute lowest temperature is approximately -20° C. At this temperature *Paulownia* stops growing.

The growth of *Paulownia* commences at an approximate temperature level of 11.5° C. Good growth rate of *Paulownia* is closely related to temperature. Experiments conducted in various places have shown that the optimum temperatures for diameter and height growth is similar, regardless of the clone or species selected. Daily mean temperatures of between 24-29° C have been shown to be the most favourable. The longer the optimum temperature lasts, the better the growth. The tree can be grown quite satisfactorily in areas with lower temperatures than this but the growth rate will be slower.

Wind
Young plants require protection from strong winds.

Altitude
As with most trees, altitude plays a critical part in the type of timber produced by the *Paulownia*. The growth rate between sea level and *Paulownias'* maximum altitude of approximately 2,400 meters varies in that the trees planted at lower altitudes have a marginally quicker growth rate.

Trials have shown that trees grown above 1,500 meters, although slightly slower than their counterparts at sea level, produce denser timber. This factor should be taken into account as it directly affects the end use and value of the timber e.g. with trees grown for pulp; the higher density is not as critical as those grown for saw logs or lumbers which attract a higher value.

Planting
Trees for timber should be planted at 750 per ha (300/acre) and for biomass 1960 per ha (800/acre). Detailed planting instructions are provided with the order.

(http://www.worldpaulownia-eu.com/siteselection.html)

(Accessed 11th October, 2007)

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