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Best practice prescriptions for propagating and establishing sycamore (*Acer pseudoplatanus*) for timber production

ANDREW LESLIE

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Introduction

Sycamore (*Acer pseudoplatanus*) is a naturalised exotic species in Great Britain (Peterken 2001) and is found mainly in the north and west of the country (Savill 2019). It is native to the mountain areas of central Europe (Rusanen and Myking 2003) and the date of its introduction to Britain is unknown, but it is known to have been present in mediaeval times (Jones 1945). However, there is controversy as its pollen is indistinguishable from the native field maple (*Acer campestre*), confusing the evidence from pollen records and leading some to believe it is native to Britain (Green 2005). Despite this, it is generally accepted as a naturalised and introduced species, although Natural England (2009) note that it could have arrived in Britain naturally during the last millennium from seed blown from northern France.

In Great Britain, sycamore is an important species, representing about 8% of the broadleaved woodland cover (Forestry Commission 2022a). For a deciduous broadleaved tree, it is fast-growing, achieving Yield Classes of between 4 and 12 m3 ha^{-1} y^{-1} (Whittet *et al*. 2021), with 6 to 8 m3 ha^{-1} y^{-1} being typical, and sawlogs being produced in 50 to 55 years on good sites (Stern 1982). In a shelterwood, it can provide one of the highest financial returns of a broadleaved tree due to its fast growth and high value timber (Crockford *et al*. 1987; Hein *et al*. 2009). Busby (1982) notes that sycamore, in addition to a few other broadleaves such as *Nothofogus obliqua* and sweet chestnut (*Castanea sativa*), may in some situations, provide an economically viable alternative to conifers.

Unfortunately, sycamore has acquired a poor image arising from invasive regeneration, the sticky honeydew it produces, and the relatively low level of biodiversity that it supports (Taylor 1985). This image has improved latterly (Bingelli 1994), for example, the view of Natural England has become more positive, accepting its presence will partially compensate for the loss of ash (*Fraxinus excelsior*) in ash woodlands managed for conservation (Natural England and Forestry Commission 2019). However, despite a more positive view of sycamore than in the past, there are serious constraints to growing it in Britain. The first and immediate challenge is bark stripping damage of trees between 10 and 40 years old (Mayle *et al*. 2007) by grey squirrels (*Sciurus carolinensis*) as sycamore is particularly susceptible (Rowe and Gill 1985; Joyce *et al*. 1998). A further negative impact is climate change as droughts are predicted to become more prevalent in Britain (Morecroft *et al*. 2008), making areas such as southeast England unsuitable for the species (Ray *et al*. 2010).

There is an imperative to improve the broadleaved timber resource in Britain. Sawlog volume produced per hectare in France and Germany is 15 and six times greater respectively than that of broadleaved woodland in Britain (Taylor 2019). Sycamore is a tree with potential as a timber producer, and this has encouraged this review which aims to provide best-practice guidance for seed selection, propagation, planting stock selection and establishment and protection of sycamore, which in turn it is hoped will improve the proportion of quality timber. There is, however, a paucity of strong experimental research, and silvicultural recommendations for sycamore are largely based on anecdotal observations (Hein *et al*. 2009). There is a need to validate some of the accepted practices in a formal, experimental manner. The aim of this document is to provide best-practice prescriptions for seed selection, planting stock propagation and selection, and tree establishment.

Silvics of sycamore

The site requirements of sycamore are similar to those of ash (*Fraxinus excelsior*), preferring sheltered, well-drained soils derived from basic geology, though sycamore has wider climatic and soil tolerances (Bingelli 1995; Leslie 2005; Savill 2019) (Table 1). In Great Britain, only birch (Betula spp.) and rowan (*Sorbus aucuparia*) are broadleaves known to have higher altitudinal limits (Jones 1945). However, for growing quality timber, sycamore must be planted on better sites as exposure results in shoot death and, although shoots are replaced from dormant buds, the form of the tree is affected (Bingelli and Blackstock 1997). Sycamore is relatively resistant to frost, making it suitable for planting in harsh climates (Hein *et al*. 2009) provided timber is not a main objective.

Bingelli (1994) describes sycamore as a gap species, establishing itself following disturbance or under light canopies. Sycamore will grow rapidly in full light (Hein *et al*. 2009) and is moderately shade tolerant when young. Peritan *et al*. (2007) found that sycamore requires 15% above canopy light for excellent survival, while Ammer (1996, in Hein *et al*. 2009) found good survival in light levels as low as 5%. However, sycamore requires progressively more light as it ages, losing its shade tolerance at a height of 1m (Joyce *et al*. 1998) and older trees will die if their crowns are not released from competition (Savill 2019).

Sycamore is an adaptable tree and can thrive on a wide range of sites from lowland to upland, due in part to its frost tolerance (Joyce *et al*. 1998). It is also known to grow well across a wide range of soil types, from acid brown earths to podzols and moderate gleys but not surface water gleys. The species can also tolerate calcareous soils, including those that are shallow, but does not tolerate stagnant water or flooded sites (Joyce *et al*. 1998). Further information on sycamore's soil tolerances are described in Table 1.

Exposure to wind and frost when there is a lack of shelter can kill the terminal bud resulting in forking and reducing the tree's value for timber. However, forking is also induced by terminal shoot flowering which has a major impact on tree form, while flowering in general considerably reduces vegetative growth (Bingelli 1995). Sycamore follows Scarrone's model (in Bonsen 1996) of tree growth and architecture, with growth being rhythmic and each of the limbs having the potential for unlimited growth.

Table 1. Silvicultural characteristics of sycamore.

Requirements	Details
Light	Moderately shade tolerant when young, but light demanding when older (Joyce *et al*. 1998). Described as a shade bearer requiring less than 5% light for early development (Ellenberg and Leuschner 2010).
Exposure	Can survive high levels of exposure but for timber should be grown on more sheltered sites (Bingelli and Blackstock 1997). Edlin (1967) recommends it for shelterbelts on exposed sites.
Frost	Tolerates late spring and early autumn frosts (Joyce *et al*. 1998; Gill 1992).
Soil fertility	Can tolerate a wide range of soils (Jensen et al. 2008) and is less demanding than ash (Savill 2019). It prefers soils with pH between 5.5-7.5 (Evans 1984) but can tolerate highly acidic soils where aluminium would be toxic to other trees (Weber-Blaschke *et al*. 2002). Sycamore is known to be nitrophilous (Jones 1945; Jensen *et al*. 2008).
Soil texture	There are contradictions in the reported influence of soil texture on the performance of sycamore, with Moller (1965, in Sjöstedt 2012) observing that heavy clay is tolerated, whereas Kjolby (1953, in Sjöstedt 2012) noted stunted growth and unhealthy seedlings on such heavy soils.
Soil depth	Favours soils that are deep and moist (Claessens *et al*. 1999).
Moisture requirements – seed	Seed should be kept at >40% moisture content (Gosling 2007).
Moisture requirements – tree	Jensen et al. (2008) found that sycamore would grow well on a very wide range of soils in terms of moisture content and nutrition but that best growth is on moist, well drained soils. It has low tolerance of flooding (Joyce et al. 1998), coping with flooding no longer than 30 days in duration (Hein *et al*. 2009) or waterlogging within the top 40cm of the profile (Jensen et al. 2008). It tolerates dry soil conditions better than ash (Claessens et al. 1999).

Plant production

Recommended seed sources

Provenance trials for sycamore in Britain were established in 1992, testing between eight and 10 provenances from the UK, Germany, Denmark and France. Twenty-seven-year data revealed no significant differences in growth between provenances (Whittet *et al*. 2021). This finding was supported by Helliwell and Harrison (1978) who found a lack of differences in response from five provenances of sycamore across 25 different soils. However, Cundall (1999) identified variation in bud burst in British sycamore, with origins from northern latitudes exhibiting later flushing, suggesting local adaptation. Given these contradictions, there is currently no strong evidence of local adaptation in terms of growth and survival so the normal practice of using seed zones for native trees is not appropriate when selecting planting stock (Whittet *et al*. 2021). It is recommended that for timber production, *Qualified* seed from improved seed orchards should be used (Future Trees Trust 2022). Furthermore, this seed will likely produce trees of better form and the genetically diverse material should also be more resilient to environmental change.

Occasionally, sycamore exhibits wood with a wavy grain and this can command high prices (Bolton 1949). The expression of wavy grain is genetically influenced (Quambusch *et al*. 2021) and a test of different methods for propagating this material showed that tissue culture has potential (Ewald and Naujoks 2015; Quambusch *et al*. 2021). However, to date there has been no commercial application of these findings.

Seed selection, storage and pre-treatment

The quantity of seed produced by sycamore varies across years with masting occurring every two to three years (Joyce *et al*. 1998). Seed is carried by the wind with dispersal being further than oaks, beech and limes, but not as far as ash and birch (Hein *et al*. 2009). The seed has short viability of less than a year and so for sycamore, like many shade tolerant trees, seedling banks are an important strategy to ensure successful natural regeneration (Deiller *et al*. 2003). The seed should be collected when it ripens, in September to October, indicated by it changing from green to yellow (Joyce *et al*. 1998).

Sycamore seed presents practical problems in storage and germination. Gosling (2007) describes sycamore as producing 'suicidal' seed, as they die rapidly after being shed by the mother tree. It is also unusual as its seeds exhibit being recalcitrant in addition to deep dormancy, and so drying the seed will lead to mortality, which increases below a moisture content of 40% (Gosling 2007). In contrast, Greggains (2000) states that the seed are relatively tolerant of desiccation when compared with other recalcitrant seeds, but Gosling (2007) recommends that seed be sown as soon as possible. If seed needs to be stored then it should be kept no later than the following spring, and it is recommended that it be stored at –3°C to +5°C at high humidity to reduce desiccation (Gosling 2007). These temperatures will also act in breaking seed dormancy. Joyce *et al*. (1998) note that seed can be stored for up to 2-3 years without reduced viability, but the moisture content must be reduced to 30-42% for the seed or 24-32% for the samara.

Two approaches to pre-treatment are described in Joyce *et al*. (1998), one with a stratification medium and another without, and these are described in Table 2. An experiment was established testing germination in two environments (glasshouse and nursery) with three treatments: (1) immediate autumn sowing; (2) delayed sowing in spring after a cold and moist stratification; and (3) delayed sowing in summer following a cold, moist stratification. The immediate autumn sowing provided highest germination rates and summer sowing the lowest. There were no significant differences between those sown in the nursery and those sown in the greenhouse (Yücesan and Bayram 2021). Soil temperature was also found to influence germination, with the different treatments exhibiting different optima (Yücesan and Bayram 2021). A study in the Czech Republic showed that stratification for 60 days of seed sown in a nursery medium gave best results (Stejskalová *et al*. 2014).

Raising planting stock and timing of planting

A study investigating temperature and growth of sycamore seed sown under four different coverings found that, after 90 days a covering of white polypropylene or green netting increased root collar diameter and mass of seedlings (Andersen *et al*. 1999). Potting media for containerised stock was compared in a small experiment which applied nine treatments to sycamore seedlings, and showed that the introduction

Table 2. Recommended stratification methods (Joyce et al*. 1998).*

Approach	Method
With stratification medium	Seed is sown in pits of 50:50 moist peat and sand for 4-5 weeks until 5-10% of the seeds have germinated. If sowing is to be delayed the seeds and medium can be stored for up to three months at –3°C.
Without stratification medium	Seed is placed in mesh sacks in water for 24 hours and then transferred to unsealed plastic bags and stored at 3°C. The seed is kept in the bag for 4-5 weeks and must be turned in the sack once a week so they all remain moist.

of biochar enhanced the beneficial effects of increasing compost and fertiliser application on growth after five months (Helliwell 2015).

Seedlings of sycamore are known to develop a tap root (Mackie-Dawson *et al*. 1995) but only when very young (Mauer *et al*. 2007) and so may benefit from root management in the nursery. A study of root systems of 37 tree species in the nursery and one year after being planted in the field showed that for most species, including maples like sycamore, a greater area of roots developed from the site of root pruning, rather than by initiation and extension of lateral roots (Watson and Hewitt 2020), indicating the beneficial effects of root pruning.

Bohne and Hasler (2009) compared root:shoot ratios and nutrient concentrations in roots of one-year seedlings of rowan (*Sorbus aucuparia*) and sycamore planted for a period of three years and fertilised each year, and found both were greater in sycamore. This supported the categorisation of sycamore as a stress tolerator (a tree that is competitive by overcoming environmental stresses, so resources are focused on root development) and rowan as a competitor (a tree that is highly competitive with other trees, so resources are directed at shoot development). These morphological and physical differences may support developing different nursery ideotypes and propagation regimes for trees with different ecological strategies (Bohne and Hasler 2009).

The response of sycamore seedlings to two rates of irrigation was tested for seed sown in November and watered, following cotyledon emergence, until July. Increased rates of irrigation led to increased shoot length, leaf area and dry-matter accumulation. However, changing the rate of watering after July had almost no effect (Hipps *et al*. 1996). Half the seedlings were then treated to wrenching (where a blade is passed 20cm under the seedlings) and when these were lifted in February, this technique was found to have increased the fine root length and root:shoot ratio compared with untreated seedlings. Following planting, shoot growth was highest in those seedlings that had the lower rates of watering, and wrenching made no difference. This suggests that seedlings with limited water in the nursery respond better when out planted. A series of experiments in Ireland using biostimulants on nursery bare-rooted stock was reported on by Thompson (2004). One experiment involved the application of algal compounds as foliar sprays to 1+0 (one-year-old seedling without undercutting) sycamore. After one growing season, there were significant differences in the growth of seedlings between control and treated trees (Table 3).

Table 3. The effect of spraying two algae preparations for 1 growing season on the growth of sycamore in the nursery. All numbers in a column followed by the same letter are not significantly different at the p = 0.05 level (Thompson 2004).

Treatment	Height (cm)	Diameter (cm)
Control	13.9a	4a
Kerry Algae	14.5a	3.8a
Plantali	15.5b	4.8b
% increase over control	+11.5	+10

Table 4. Recommended age, root collar diameters and heights for sycamore (Joyce et al*. 1998).*

Organisation	Maximum age (years)	Minimum root collar diameter (mm)	Maximum root collar diameter (mm)	Minimum height (cm)	Maximum height (cm)
Ireland Forest Service	3	7		40	75
British Standards Institute		4.5	6	30	50

Table 5. Minimum root collar diameter (mm) and cell volume (cc) for cell-grown broadleaved trees (Morgan 1999).

	Height range (cm)			
Attribute	10-20	20-40	40-60	60-90
Minimum root collar diameter (mm)	4	4	6	8
Minimum cell volume (cc)	50	100	150	200

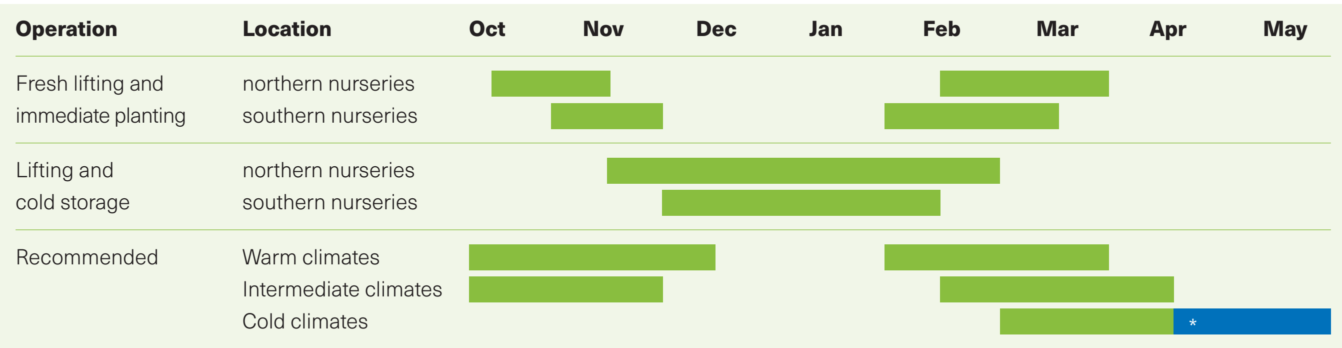
Date of lifting of bare-rooted stock has a strong influence on successful establishment. A study conducted by O'Reilly *et al*. (2002) showed that sycamore became active earlier in the year than ash (*Fraxinus excelsior*), i.e. in February or March, rather than April or May. However, survival of freshly lifted bare-rooted sycamore did not vary by time of lifting.

If planting bare-rooted stock, then Evans (1984) recommends robust 1+1 seedlings between 25 to 50cm in height for broadleaves in general. To ensure planting stock has a healthy root:shoot ratio, the size specifications for bare-rooted sycamore is described in Table 4 and for cell-grown broadleaves in general in Table 5, as there are no specific recommendations for sycamore. The specifications for bare-rooted trees differ between Ireland and Britain (Table 4).

Timing of planting has a strong influence of the establishment of seedlings with Evans (1984) recommending that broadleaves be planted between late September and the middle of November, during damp, relatively mild weather, and for bare-rooted stock no later than May. A study of sycamore and ash growth and time of planting showed that for sycamore, height growth was greatest in seedlings planted between September and early March O'Reilly *et al*. 2002). This follows the recommendations in Morgan (1999) (Figure 1), which largely conform to Evans' (1984) recommendations. However, it contrasted with ash that grew most rapidly when planted between early October to November or after February (O'Reilly *et al*. 2002).

Cell-grown stock of sycamore is also used in Britain but there are no published studies on nursery performance and container shape and volume.

*Figure 1. Timing of nursery and planting operations in relation to location: northern nurseries - Onset of dormancy is early and release from dormancy is late, southern nurseries - Onset of dormancy is late and release from dormancy is early. Cold climates – northern England, Scottish and Welsh mountains (Accumulated temperature <1050 degree C days), Intermediate climates - northern England, Scottish and Welsh uplands (Accumulated temperature 1050 - 1350 degree C days), warm climates – Most of England and Wales and coastal areas of southern Scotland (Accumulated temperature >1350 degree C days) (Morgan 1999). * only cold stored material should be planted in this period.*



Establishment

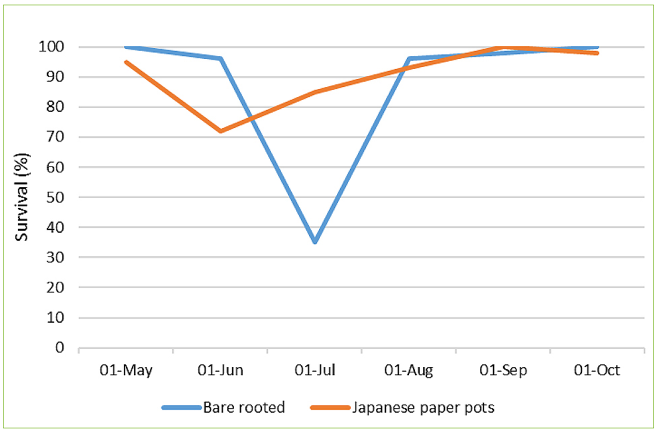
Site selection

The general site requirements of sycamore are described earlier in Table 1. For quality timber, sites with fertile and moist soils are required, although it will tolerate a wide range of sites, including very exposed ones (Bingelli and Blackstock 1997). Southerly aspects are preferred to northerly ones (Bolton 1949). The areas suitable for growing sycamore as a timber tree across Britain are predicted to shift due to climate change with the south-east of England and the Midlands becoming less suitable while parts of south-east Scotland will become more suitable (Ray *et al*. 2010). A survey of growth on 34 stands in Denmark showed that increasing soil clay content on well-drained soils and nitrogen concentration in general, improved growth, while increasing soil carbon reduced growth (Jensen *et al*. 2008).

Planting material selection

In normal circumstances, bare-rooted and containerised stock, when planted, performs similarly in growth and survival (Evans 1984). In a trial of bare-rooted versus container-grown (Japanese paper pots) trees of four species, and investigating survival, containerised trees only had an advantage when planted in summer (Evans 1984). In another experiment, differences in growth and survival between different planting stock and different sites showed no clear trend so Kerr (1994) recommends developing a plant quality index that captures the ideal morphological and physiological plant characteristics instead of focusing on containerised versus bare-rooted stock.

Figure 2. Survival of bare-rooted and containerised stock planted at 28 day intervals over the growing season (Evans 1984).



Nutrition

Sycamore is considered to be a nitrophilous species (Jones 1945; Jensen *et al*. 2008). However, a study comparing beech, Norway maple (*Acer platanoides*) and sycamore showed that beech was more effective at capturing nitrogen in a poor soil than the other two species (Simon *et al*. 2010). Another study showed that sycamore and beech prefer uptake of different nitrogen compounds in the soil, with sycamore showing a preference for NH4+ and beech a preference for NO3– (Jacob and Leuschner 2015).

The importance of nutrition for root growth was demonstrated in an experiment by Mackie-Dawson *et al*. (1995) who grew two-year-old seedlings planted into large pots under low and high nutrient regimes. Low levels of nutrients resulted in a high root: foliage ratio, while the high nutrient treatment resulted in a larger root mass and root diameter overall. High calcium (Ca) and magnesium (Mg) and low aluminium (Al) concentrations resulted in rapid growth of sycamore, but in soils with lower concentrations of Mg and Ca, growth was reduced due to Mg deficiency. In soil with low Mg and low Ca, but high Al concentrations, both Ca and Mg were found to be deficient (Weber-Blaschke *et al*. 2001).

Mycorrhizae may offer an alternative to fertilisers in improving tree nutrition by increasing water and nutrient uptake, but there are site constraints. It is known that the level of infection of sycamore by mycorrhizae is linked to the characteristics of the soil (Helliwell 1973; Weber and Claus 2000) such as pH, organic matter, phosphorous and iron (Frankland and Harrison 1985) and levels of Ca (Helliwell 1973). Weber and Claus (2000) found that the transition from high pH, high nutrition media in the nursery to acidic soils in the field disrupted mycorrhizal associations in sycamore. The seedlings were found to be deficient in Mg and Ca on these acidic soils. There was also evidence that nitrogen input decreased mycorrhizal activity in these acid soils. Soil aluminium was found to disrupt Mg and Ca uptake (Weber and Claus 2000; Weber-Blaschke *et al*. 2011).

Also, the benefits to the tree from mycorrhizae are likely to be dependent on the fertility of the soil, particularly the phosphorous content. A greenhouse experiment comparing uninfected seedlings with those infected with the mycorrhizae *Glomus mosseae* found that phosphorous uptake and growth was only enhanced in the soils with lowest phosphorous concentrations. At 200 ppm, phosphorous-inoculated seedlings reduced growth (Brechet and le Tacon 1984). This was contradicted however by another greenhouse experiment that showed that inoculation with *G. mosseae* or a mycorrhizal complex from a sycamore stand increased growth even in rich soils (Kabre *et al*. 1982).

Controlling competing vegetation

Sycamore is known to be very sensitive to competing vegetation (Ammer and Weber 1999, in Hein *et al*. 2009), particularly grasses, and should be weeded until at least 1 m in height (Joyce *et al*. 1998). The strong effect on growth from weed competition is illustrated in Table 6 and Table 7.

Table 6. The effect on growth and survival of different sized weed control spots (Davies 1987).

Attribute	Weeded spot diameter (m)			
	0	0.54	0.76	1.04
Survival	78	97	96	91
Height growth (cm)	58	75	86	100
Basal area growth (mm2)	101	160	210	287

Protection

Seedlings of sycamore must be protected as they are palatable to a range of deer species, including roe (*Capraeolus capraeolus*), fallow (*Dama dama*), red (*Cervus elaphus*) and Sika (*Cervus nippon*) (Gill 1992). These browse the foliage and young shoots. Sensitivity of sycamore to browsing is similar to ash (Kupferschmid and Bugmann 2008) and greater than beech (Modrý *et al*. 2004). Ferris and Carter (2000) placed common broadleaves in the following order of palatability from highest to lowest: willows, ash, oak, rowan, Norway maple, sycamore, beech, lime, hornbeam, birch and alder, but other studies suggest it is highly palatable (Modrý *et al*. 2004). A clipping experiment to simulate browsing on seedlings of four tree species including sycamore, showed that after five years sycamore survival was significantly lower in clipped trees (Harmer 2001). Rabbits (*Oryctolagus cuniculus*) and hares (*Lepus* spp.) will also damage young trees (Joyce *et al*. 1998) by excising the leader of branches. Bolton (1949) has noted damage by rabbits to bark of pole stage trees in spring following severe winters, and attributes this to the feeding of the rabbits on the rising, sugary sap.

Tree shelters can be used to protect seedlings against damaging mammals, but they are also recommended as a means of increasing early height growth and survival. Height of sycamore at three years old in shelters is increased by over 100% compared with trees in mesh guards (Potter 1999). However, tree shelters reduce basal area growth and the volume of young trees in shelters and out was not significantly different after two years (Davies 1985) (Table 7).

Cultivation and other site modifications

There is little information on cultivation but recommendations for suitable cultivation for different soil types in the UK have been presented in Haufe (2020) and these apply to sycamore. There has been some research on soil conditioners. On two sites in the Czech Republic,

Table 7. The effect of different sized spot herbicide treatments and tree shelters on the establishment of sycamore transplants after two years (Davies 1985).

Attribute		Weeded spot diameter (m)			
		0	**0.25**	**0.5**	**1**
Height growth (cm)	Without shelter	40	45	50	63
	With shelter	70	86	105	114
Basal area growth (mm2)	Without shelter	41	60	97	168
	With shelter	25	44	62	86
Volume index	Without shelter*	23	34	53	100
	With shelter*	25	39	60	80
Survival (%)	Without shelter	81	66	92	97
	With shelter	89	98	100	95

* Without and with shelter not significantly different

the influence on early growth of sycamore of three soil conditioners (TerraCottem, Agrosil LR and Hydrogel) were tested (Sloup and Salaš 2006) with Hydrogel, a water-retaining compound, significantly improving height growth by the end of the first growing season.

Planting patterns and use of mixed species stands

Sycamore has only moderate self-pruning ability (Joyce *et al*. 1998) and the recommendation from Forest Research's Forest Development Types is that sycamore be planted at between 3,000 – 5,000 stems ha^{-1} for timber (Haufe *et al*. 2021). Joyce *et al*. (1998) recommend planting at 4,000 stems ha^{-1}, with a spacing of 2m between rows and 1.5 m within rows. In contrast, Moller (1965, in Sjöstedt 2012) recommends 2 m x 2m (2,500 stems ha^{-1}) and Orde-Powlett (1923) proposes 2.2m spacing. Current grant funding in England does not fund stocking densities of more than 2,500 stems ha^{-1}, although applications will be considered for woodland creation at higher densities (Forestry Commission 2022b).

Shelter is conducive to the establishment of sycamore. Joyce *et al*. (1998) describe sycamore as not requiring nursing but side shelter was shown to significantly increase growth, even on relatively sheltered sites in the lowlands in the UK, and in discussions with foresters, shelter was identified by Jensen *et al*. (2008) as being important to sycamore growth. Jensen (1984, in Sjöstedt 2012) recommends planting only in coupes of less than 1 ha to ensure side shelter from adjacent stands. Willoughby *et al*. (2009) recommend that a nurse species be considered in early establishment as a more cost-effective alternative to using tree shelters.

Sycamore normally occurs in mixed species stands and its success in mixed stands arises from two characteristics: prolific natural regeneration and its rapid initial height growth (Hein *et al*. 2009). For plantations, Bolton (1949, p164) recommends establishing sycamore in mixture and states that he has 'never seen a successful stand of pure sycamore'. He notes that this is because, for good quality sycamore, side shade is needed to control branching and this is best achieved through competition with other tree species (Bolton 1949). There are other good economic reasons for using mixed stands as early thinnings from sycamore do not have a market, and so Bolton (1949) recommends a mix with a species that has markets for its small roundwood.

There are several recommendations for establishing sycamore in mix with other species. Hein *et al*. (2009) describe mixed stands of sycamore with beech (*Fagus sylvatica*), ash or oak, while Joyce *et al*. (1998) recommend ash, and Orde-Powlett (1923) and Bolton (1949) recommend mixes with beech or Norway spruce (*Picea abies*). A mixed stand of sycamore and larch (*Larix* spp.), with a proportion of five larch to one sycamore being recommended at planting with the ultimate goal of creating a final stand of sycamore, is a traditional approach that has been practiced for decades at the Bolton Estate (Bolton 1949). This mixture provides side shade for the sycamore and also an insurance against damage, such as grey squirrel to sycamore, to one of the components (Bolton 1949). In later years there will need to be intervention to maintain the mixture as the larch will grow more rapidly than the sycamore. However, both larch and ash are not currently recommended for planting due to the action of damaging pathogens (Forestry Commission no date; Forestry Commission 2020). As a planting pattern, Joyce *et al*. (1998) recommend that sycamore in mixes be planted in groups of at least 100 m2 in area within a matrix of the other species as this provides greater future management flexibility.

Sycamore has stronger apical dominance than species such as oak and beech but a major impact on the form of young sycamore is flowering, which causes a fork in the stem of branches bearing the flower (Cundall 1999). Bolton (1949) recommends that formative pruning is essential in maintaining a single leader, as sycamore has a tendency to develop two or more leaders. Joyce *et al*. (1998) recommend formative pruning to improve form at 2-3 m and then at 4-5 m top height.

Conclusions

During this review it became apparent that there are considerable gaps in our knowledge of raising and establishing stands of sycamore for timber production. If the damaging activity of grey squirrel can be controlled, sycamore offers a resilient and productive choice of species when growing broadleaves for timber.

Recommendations

- While it is tolerant of poor sites and exposure it can only be grown for timber on better sites.
- Seed used for nursery stock, should be sourced from seed orchards and if planted within the planting season, bare-root and cell-grown stock seem to perform similarly. If poor handling or out-of-season planting is likely, then cell-grown stock should be preferred.
- Sycamore is a nitrophilous species and would therefore benefit from application of fertiliser on poorer sites.
- Sycamore is palatable to a range of mammals that browse its foliage and strip its bark so protection is important.
- It is also highly intolerant of weed competition so weeding should continue until the trees are approximately 1 m tall.
- Tree shelters offer protection from mammal damage and herbicide spray, and increase tree height, but not young tree volume.
- When establishing sycamore for timber, to ensure good growth and form it should be sheltered and so establishing it in mixed stands should be considered.
- To encourage a stand of high timber quality to develop, formative pruning of selected trees should be practiced when at the pole stage of development.

Further research

Hein (2009) in his excellent review noted that there is a lack of experimental research to support silvicultural recommendations for sycamore and so they are based mainly on experience and informal observations. There are many areas where further research would be of benefit.

There are opportunities to develop best-practice prescriptions for raising bare-rooted and cell-grown planting stock. Sycamore is a 'stress tolerator' i.e. it allocates a higher proportion of resources to root growth than shoot growth when young, compared with trees categorised as 'competitor' species. This should be reflected in nursery propagation methods.

The benefits from mycorrhizae and the optimum mycorrhizal species for sycamore growth on a range of sites has not been clarified.

For sycamore, the use of tree shelters is to boost height growth at the expense of diameter growth. It may be that a different type of shelter may produce taller trees of equal or greater volume than those grown outside shelters. The effect of increasing tree height while reducing tree diameter of traditional shelters should be investigated on drier sites or in times of drought.

Sycamore grows well in mixed stands, where the companion species can provide competition and moderate branch growth. There are opportunities to investigate the effect of different companion species on growth and quality of sycamore, and to find replacements for larch and ash as associated species in mixes.

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Harwell Innovation Centre,
Building 173, Curie Avenue, Harwell, Oxford, OX11 0QG
07896 834518 • info@futuretrees.org • www.futuretrees.org