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RESEARCH ARTICLE

Silvicultural aspects of the sycamore (*Acer pseudoplatanus* L.) propagation – Overview

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Abstract
The purpose of this study is to analyze existing silvicultural experience related to the sycamore using literary data in order to optimize future work with the species. The discussion looks into matters related to: ecological requirements, seed propagation, vegetative propagation via rooting of stem cuttings and grafting, natural regeneration specifications, creating and cultivation of forest plantations, growth and productivity of the stands, and silviculture activities dedicated to the production of high-quality timber.

Keywords
regeneration, cultivation, fertility, silvicultural systems

Introduction

The sycamore (*Acer pseudoplatanus* L.) is one of the most important species of *Acer* genus in terms of forest management (Pandeva, 2004). Information on its economic qualities are reported by Vahide (2009); Soulères (1997); Joyce et al. (1998); Hein, Spiecker (2008); Hein et al. (2009); Pasta et al. (2016). There is an accent on the environment-shaping qualities of the species (Stern, 1989; Bingelli, 1993; Pommerening, 1997; Heitz, Rehfuess, 1999; Bell, 2009). It grows well in a wide spectrum of ecological conditions (Vahide, 2009; Joyce et al., 1998; Hein et al. 2009), saline (Joyce et al., 1988) and eroded soils (Pasta et al., 2016), and it shows adaptability to climate shifts (Vahide, 2009; Kölling, 2007; Kölling, Zimmermann, 2007). Based on these arguments

Spiecker et al. (2008) recommend that the sycamore gains a wider use in European forestry.

The purpose of this study is to analyze existing forestation and silvicultural experience related to the sycamore using literary data in order to optimize future work with the species.

Ecological requirements

The habitat of the species covers most of Bulgaria's territory, with the species generally highly present in the northeastern region (Pasta et al., 2016). It can be found mostly in mixed deciduous forests, sporadic singular instances or in larger groups – in all mountains, in fresh habitats above 1400 m a.s.l. (Milev et al., 2004). It takes up a total of 2324.42 ha (Varbeva, 2019).

The sycamore prefers humid, cool mountain climate (Jouce et al., 1998). The optimal annual rainfall is 500-1500 mm (Pasta et al., 2016). Habitats with high atmospheric humidity and soil moisture can make up for insufficient rainfall (Joyce et al., 1998). The information on how the species reacts to late spring and early autumn frost is inconsistent. According to Vahide (2009), Gill (1992), Joyce et al. (1998), Piovesan et al. (2005), the species tolerates it fairly well, which makes it popular with foresters in cases of canopy thinning, when the afforestation of stands is generally slow or difficult due to bad climate conditions. However, Suszka et al. (1996) and Skovsgaard, Jørgensen (2004) claim that the species is sensitive to the cold spells in late spring and early autumn.

When it comes to soil, the sycamore is quite demanding. It prefers deep, fertile, moist and ventilated soils that mix sand and clay (Suszka et al., 1996), with wide range of acidity (Joyce et al., 1998; Pasta et al., 2016). In general, the species can grow well in various types of soil (Joyce et al., 1998).

In Bulgaria, the species is an indicator of medium deep and deep soils, fresh and humid habitats, usually in a shady area. Such types of soil are typical for the deciduous mesophilic and mixed forests in altitude ranging between 200-1400 m (Varbeva, 2019).

Seed propagation

Free-range sycamore trees usually become fertile somewhere between the age of 11 (Milev et al., 2004; Iliev et al., 2015) and 25 (Suszka et al., 1996; Joyce 1998), and when in stands – between the age of 25 (Milev et al., 2004; Iliev et al., 2015) and 30 (Suszka et al., 1996; Joyce, 1998). There is annual high quality harvest (Iliev et al., 2015), but it is only abundant every other 1-2 years (Milev et al., 2004), when the tree is between 40 and 60 years old (Hein et al., 2008). The crop is ready during September-October (Bertels, 2012; Stilinović, 1985; Suszka et al., 1996) and does not disseminate during the autumn (Suszka et al., 1996; Joyce et al., 1998). It is harvested during the period of September-November (Krüssmann, 1997) when the humidity of the fruit is 30-58% (Milev et al., 2004; Iliev et al., 2015; Suszka et al., 1996; Joyce et al., 1998). The sowing materials have high humidity and are prone to spoiling easily (Milev et al., 2004; Hong, Ellis, 1990). According to Milev et al. (2004), Iliev et al. (2015), in case the humidity falls below 30% the seeds perish, while Suszka et al. (1996) claims that the minimum whole-fruit-humidity needed is 24%.

The yield reaches 80-90% (Milev et al., 2004). The seed material is hard to flow and that is why it is recommended that the samaras be removed beforehand (Milev et al., 2004; Bertels, 2012). The mass of 1000 seeds is 85-95 g on average (Stilinović, 1985), and it varies from 70 to 221 g (Joyce et al., 1998, Stejskalová et al., 2014), with 1 kg containing 6000 to 14000 samaras (Milev et al., 2004). The viability of the seeds varies from 50% to 70-80% (Milev et al., 2004; Iliev et al, 2015; Varbeva, 2019) and can last for a period of two years (Milev et al., 2004; Iliev et al., 2015; Stilinović, 1985). According to Suszka et al. (1996), germination can reach 95% in separate cases.

A decrease in humidity is not required during a winter-long storage, but if the storage lasts for up to 2-3 years, then the humidity needs to be decreased to 24-32% (whole fruits), or 30-42% (seeds) in a controlled temperature ranging from -3 to -5 °C (Suszka et al., 1996). There are claims that the seeds can be stored for up to 6-7 years (Joyce et al., 1998).

As the seeds become ripe, they fall into a physiological rest (Milev et al., 2004; Bertels, 2012; Iliev et al., 2015; Varbeva, 2019; Dirr, Heuser, 1987; Krüssmann, 1997; Joyce et al., 1998; Hartmann, 2010; Stejskalová et al., 2014). The presence of inhibitory substances in the seed shells is possible (Milev et al., 2004; Iliev et al., 2015; Hong, Ellis, 1990).

Recommendations for sowing the material in its physiological maturity is a relatively rare find in literary sources (Bertels, 2012). A recommendation for autumn sowing can be found much more often (Dirr, Heuser 1987; Joyce et al., 1998), with the seeds taking a preliminary, week-long soak in water (Baskin, Baskin, 1998; Hartmann, 2010). The seeds germinate prematurely in early spring causing their sprouts to freeze (Joyce et al., 1998). This is why a spring sowing of stratified seeds is recommended in the literary sources (Varbeva, 2019).

For springtime sowing it is recommended that the seeds be stratified within 0-5 °C for a period of 3 weeks to 3 months (Milev et al., 2004; Bertels, 2012; Iliev et al., 2015; Varbeva, 2019; Dirr, Heuser, 1987; Suszka et al., 1996; Krüssmann, 1997; Baskin, Baskin, 1998; Joyce et al., 1998; Dirr, Heuser, 2006; Hartmann et al., 2010; Stejskalová et al., 2014) and mean humidity of 44-50% (whole fruits) and 50-58% (seeds) (Suszka et al., 1996; Baskin, Baskin, 1998). For fruits with lower pericarp humidity below 12%, Bertels (2012) suggests a hybrid of warm and cool stratification, with a month-long warm phase at 20 °C, or a 48h soak in water at 40 °C.

Premature germination is possible after the 20th day (Milev et al., 2004, Iliev et al., 2015; Varbeva, 2019). When 5-10% of the seeds germinate before sowing is possible, they can be conserved for up to 3 months at -3 °C (Joyce et al., 1998).

The furrow sowing rate is 32.5-490 $g.m^{-1}$ and for free sowing – 80-100 g/m^2 (Suszka et al., 1996). Furrow sowing is the regular practice in Bulgaria with density of 4.4 $g.m^{-1}$ (Iliev et al., 2015).

The production norm in furrow sowing is 100 $s.m^{-1}$, and in free sowing – 300-500 $s./m^2$ (Suszka et al., 1996; Krüssmann, 1997), or an average of 25-30 one-year-old saplings, or 20 two-year-old saplings per 1 m (Iliev et al., 2015).

Vegetative propagation

Vegetative propagation in sycamores is carried out through the rooting of stem cuttings and grafting (Dirr, Heuser, 1987).

The sycamore is difficult in terms of stem cutting rooting. The formation of adventitious roots depends largely on the abilities of the genotype (Vahide, 2009). According to Dirr, Heuser (1987) the developmental stage of the donor is of key significance, with cloning of mature donors virtually impossible using this method.

For optimal donor phenophase state, it is recommended that the shoots be green, obtained immediately after spring vegetation (Bertels, 2012), or semi-woody (Bertels, 2012; Spethmann, 2007; Hartmann, 2010), obtained in June.

The length of the cuttings can vary between 28 and 35 cm (Hartmann, 2010).

An exogenous supply of auxin in the form of powder, paste, water or spirit solution with 5000-20000 $mg.l^{-1}$ concentration (Vahide, 2009; Bertels, 2012; Spethmann, 2007; Hartmann, 2010). The concentration of the auxin supplement depends on the features of the donor species and its developmental stage (Dirr, Heuser 1987; Hartmann et al., 2010).

The environmental conditions are of high consequence to the rhizogenesis. Peat is used as a substrate (Hartmann et al., 2010) or a mixture of 2/3 parts peat and 1/3 perlite (Varbeva, 2019; Thompson et al., 2001). High air humidity is maintained via a fog system (Spethmann, 1982; Dirr, Heuser, 1987; Thompson et al., 2001; Hartmann et al., 2010). Thompson et al. (2001) pinpoint a regiment where the system is activated for 18 seconds every 30 minutes from 07:00 to 20:00 on a daily basis. Good results would also require soil heating (Bertels, 2012).

Enrooting of cuttings can reach up to 49%. There is some experience in rooting rejuvenated cuttings obtained from grafted trees. Only 24% take root, probably due to the rapid ontogenetic aging of grafted trees (Thompson et al., 2001).

Enrooting is greatly facilitated when the donor plants are pruned and shaded before the cuttings are harvested (Maynard et al., 1996). Etiolation of shoots or lack of light can improve the enrooting rate of species that are normally characterized by difficult vegetative propagation (Maynard, Bassuk, 1985, 1987, 1990, 1996; Miske, Bassuk, 1985; Podaras, Bassuk, 1996; Sun, Bassuk, 1999; Amissah, Bassuk, 2007). Varbeva (2019) reports a post-etiolation enrooting rate of young donors of up to 72%.

In summary, it can be said that the sycamore is a difficult to enroot species. This biological feature determines the significance of grafting (Varbeva, 2019).

The main prerequisite for the success of grafting is the genetic compatibility between the components. Krüssmann (1997) and Hartmann et al. (2010) divide the representatives of the *Acer* genus in two groups of genetic compatibility: those that ooze milky white sap and those that do not. On this basis, *A. pseudoplatanus* is compatible with *A. heldreichii*, *A. trautvetteri* and others. According to Bertels (2012) and Dirr, Heuser (1987), rootstocks of the same species are used for grafting the sycamore – most often 2-year-old seedling saplings (Dirr, Heuser, 1987; Thompson et al., 2001; Grbich, 2004).

The components are in optimal phenological condition in two calendar periods – late winter to early spring (January-March) and summer (June, July, August), after the completion of height growth and development of summer wood (Bertels, 2012; Dirr, Heuser, 1987; Krüssmann, 1997; Thompson et al., 2001; Shmid, 2002; Grbich, 2004;). In the first of the two periods, the rootstock must be in a state of active sap movement, and the grafts must be in a state of dormancy (Shmid, 2002). Dirr, Heuser (1987) and Thompson et al. (2001) specify that both components may be at rest during this period.

Hartmann et al. (2010) suggest the use of container seedlings, which are moved to a greenhouse at the end of winter to start earlier vegetation.

When the bark of the rootstocks is not separated from the wood, an alternative is bud grafting in a lateral cut, grafting by simple, improved copulation, lateral grafting (Krüssmann, 1997; Hartmann et. al., 2010) or an incision (Thompson et al., 2001). If it is possible to separate the bark, bud grafting can take place via a T-shaped incision (Varbeva, 2019).

To avoid drying when copulating, there should be one bud on the rootstock and one on the graft, against the cut (Krüssmann, 1997).

The intergrowth time of the components is about 35 days. After grafting during the vegetation season, the shoots on the rootstock are removed (Bertels, 2012). Information is indicated as to a successful component intergrowth rate of 93%. (Varbeva, 2019; Thompson et al., 2001; Hartmann et al., 2010).

Features of natural regeneration

The sycamore has great regeneration potential due to the frequent abundant, good quality harvests, the adaptability of the sprouts in varying light modes, and its strong competitiveness (Jensen, 1983; El Kateb, 1992; Ammer, 1996a; Joyce et al., 1998; Kazda et al., 1998, 2000, 2004; Messier et al., 1999; Tillisch, 2001; Diaci, 2002; Deiller et al., 2003; Hérault et al., 2004; Skovsgaard and Jørgensen, 2004; Dreyer et al., 2005; Collet et al., 2008; Hein et all., 2009; Caquet et al., 2010).

An important factor for the survival of the saplings is the competition with the grass cover (Ammer, 1996a, b; Joyce et al., 1998; Diaci, 2002; Modrý et al., 2004) and the chance of wildlife-induced damage (Mosandl, El Kateb, 1988; Gill, 1992; Ammer, 1996b; Harmer, 2001; Bertolino, Genovesi, 2002; Diaci, 2002; Modrý et al., 2004; Kupferschmid, Bugmann, 2008; Hein et al., 2009).

The sycamore has the ability to develop stump shoots quickly after being cut down, which explains its presence in forest stands after the final phase of felling. (Bryndum, Henriksen, 1988; Henriksen, Bryndum, 1989; Tillisch, 2001).

Creating forest crops

The common maple in Bulgaria is traditionally included in the composition of mixed crops as a second or third type of oak, beech, pine, spruce and other crops with participation 5/10 – 8/10 (EFA, 2013). In Europe, there is information about positive development in mixed crops with ash and European larch. The recommended way of mixing is in rows or group-mosaic, with an arrangement scheme of 2x1.25 m for the sycamore and 2x2 m for the European larch. In group-mosaic mixing, the size of the groups should be at least 100 m^2 (Joyce et al., 1998).

Joyce et al. (1998) recommends an arrangement scheme with row spacing of 2 m and a distance between the saplings in the row of 1.25 m or 4000 $pcs.ha^{-1}$. According to Regulation №2 of 07.02.2013, row arrangement schemes are applied with row spacing of 2.0-3.0 m and a distance of 1.0-1.5 m or 3500-5000 $pcs.ha^{-1}$ within the row. The method of mixing is a single line in rows and row-belts, less often – belts.

Interspecific relations

Due to environmental and anthropogenic factors that are difficult to separate, the sycamore is rarely found in pure stands (Merton, 1970). The ability of the sycamore to grow in mixed stands stems from two of its characteristics: it easily regenerates naturally and can establish temporary dominance due to its rapid growth at a young age. These two characteristics allow it to grow well in microclimatic conditions optimized by other species (Hein et al., 2009).

An important issue in the cultivation of the sycamore with other species in rich habitats, is its competitiveness (Waters, Savill, 1992; Skovsgaard, Jørgensen, 2004; Skovsgaard, Henriksen, 2006). There exists the notion that if its development isn't regulated, the mixed stands can evolve into pure sycamore stands within one or two rotations (Hein et al., 20019).

On limestone plateaus in Western and Central Europe, the common maple is found as a companion species in stands dominated by beech or oak. These stands have the potential for great species diversity due to the great spatial heterogeneity of soil conditions. Norway maple, field maple, hornbeam, European ash, cherry, *Sorbus* and linden members can all be found in the mix (Decocq et al., 2005). The sycamore can dominate the habitat in stands with good moisture retention, but in dry habitats it is seldom found. In deep, slightly acidic, drained soils, the sycamore grows in mixed stands in the company of the same other species (Hein et al., 2009).

European beech is the most common companion of the sycamore (Bartelink and Olsthoorn, 1999; Piovesan et al., 2005). The sprouts of both species have similar light requirements and show identical growth in shaded or partially shaded areas in the first few years (Beck, Göttsche 1976). The sycamore can be used to protect the undergrowth of the European beech from frost in its initial stage of development (Joyce et al., 1998).

However, when the canopy is removed and the saplings are fully exposed to sunlight, the sycamore grows much faster than the European beech and quickly catches up (Beck, Göttsche, 1976). This advantage can be observed until the age of 50 (Joyce et al., 1998) or 60-80 years (Schober, 1995; Hein, 2004). If the goal is to preserve the sycamore in the mix, then beyond this point it will be necessary for European beech trees to be removed, because they overshadow and compete with the sycamore. (Skovsgaard, Henriksen, 2006). Alternating rotations of dominance between one, and/or the other species can be maintained as another option (Skovsgaard, Henriksen, 2006).

The sycamore and the European ash exhibit similar ecological requirements and growth dynamics (Waters, Savill, 1992). Both species' requirements for light increase in accordance with their age. Their common environmental requirements are reflected in similar growth curves in height (Le Goff, 1982; Hein, 2004), which makes controlling their growth in mixed crops easy. As an adult tree, however, the sycamore casts a deeper shade than the European ash and this gives it the advantage of fresh habitats. In drier habitats, however, the sycamore often grows more slowly than the European ash (Morecroft et al., 2008). A study on the regeneration process of the sycamore and the European ash by Waters, Savill (1992) in the south of the UK, showed that the replacement of trees forming the canopy is cyclical rather than serial, although this is not a common trend (Morecroft et al., 2008).

In stands mixed with oaks, the sycamore has advantages over the oaks due to its faster growth rate at a young age and its greater shade tolerance. If the sycamore is single, there is no need to control the composition, but if it is takes up a larger area, it should be controlled so as not to displace the oaks which would be preferred (Hein et al., 2009).

In mountain forests, the sycamore can be found in mixed stands in a wide range of habitats (Piovesan et al., 2005). It is often a secondary species in stands dominated by spruce, fir or beech, where it shows good growth (Ammer, 1996a). In the Bavarian Alps, the participation of the sycamore in such stands varies between 10 and 15% of the circular area, and spruce, fir and beech account for 20 to 40% (Ammer, 1996a). The deep, powerful root system of the sycamore allow it to also thrive on unstable, rocky slopes along with lindens and European ash. (Hein et al., 2009).

The sycamore and the silver fir exhibit great shade tolerance at a young age. The other trends in their growth are quite different. The sycamore is quicker to react to improved growth conditions (Ammer, 1996a). In even-aged stands it often outperforms the silver fir in its early stage, but due to its shade tolerance, the fir eventually catches up. During the late phase, fir trees can pierce through the sycamore canopy and therefore – suppress it. The silver fir in such stands is usually grouped together, which renders further control measures unnecessary. According to Pretzsch (2005) mixed stands that consist of photophilous sycamore trees and shade-tolerant silver fir, are an example of positive inter-species interaction.

In mixed freshwater swamp forests, after extreme periods of flooding along the Rhine between Germany and France, the survival of sycamore trees increases with the growth of the tree diameter and decreases with the increase of the flooding period and the water level. The flood resistance of the sycamore is much lower than that of field ash, poplar, oak, willow and elm, but greater than that of beech and cherry Hein et al. (2009). Späth (2002) sets 30 days as the maximum period of the sycamore's tolerance to flooding.

Forking has a substantial negative effect on the quality of timber. The forking is induced any time the central shoot blossoms. Growth felling is aimed at reducing the competition in favour of the crooked and forked specimens.

For the conditions of Ireland, thinning out is recommended when the saplings are at the height of 7-8 m to a density of 2200 pcs.ha^{-1}. If the aim is to support the undergrowth of shade-tolerant species (common beech or hornbeam), then it will be necessary to space out the sycamore when it reaches a height of 12-14 m. The ultimate goal is to select about 150 individuals for future breeding at a height of 15-30 m or at a density of about 650 ha-1 (Joyce et al., 1998).

In conclusion, it is safe to claim that there are good conditions for the growth of the sycamore in mixed stands that are known in the field of forestry. Even so, detailed information on its sensitivity to certain environmental factors (habitat richness, drought, climate change, wildlife-induced damage) in combination with major forestry interventions, is not available. This hinders our understanding of the sycamore's dynamics in mixed stands, barring the development of forestry manuals, adapted to this type of stands (Hein et al., 2009).

Growth and productivity

Information on the sycamore's growth rate in different parts of Europe comes from various sources: Lessel, (1950), Kjølby (1958), Hamilton, Christie (1971), Lockow (2004), Anonymous, (1984) (according to Hein et al., 2009).

Hein et al. (2009) indicate that all height growth curves are characterized by the same quality: quick growth rate during the early stages (20-25 years), which eventually slows down after the growth. In some of the best habitats the species can reach up to 19.5 m within its 20th year (Claessens et al., 1999). In poor, dry habitats, the lowest height hits 6.5 m (Anonymous, 1984, according to Hein et al., 2009).

The sycamore hits its optimal growth in diameter at an age younger than 10 years, while its growth rate is undisputed by the competition (Hein et al., 2009). The growth in height and diameter hits its peak around the age of 20-25 (Spiecker, 1991).

Hemery et al. (2005) use the connection between the width of the crown and the diameter at chest level, in order to calculate the optimal distance between the specimen or the survival rate for the European ash, the common cherry and the sycamore.

Hein, Spiecker (2008a) offer a more comprehensive account of the diameter/crown correlation in the sycamore. Including age as an independent variable in the relationship between crown width and diameter may explain the difference in crown width between fast-growing and slow-growing tree species that can be observed. Trees that grow faster in diameter reach a certain diameter faster than those that grow more slowly. When the slow-growing trees reach the same diameter, their crown is significantly larger than that of the fast-growing trees with the same diameter. This is further confirmed by the research of Hasenauer (1997), Condés, Sterba (2005) and Hein, Spiecker (2008b) on independently growing trees: such trees that grow without competition have a wider crown diameter for every trunk diameter, compared to the ones in dense stands.

Despite that, however, this correlation is different in the sycamore from the one in the European ash, oaks and cherry trees (Hein, Spiecker, 2008a). At the same age and trunk diameter, the dominant sycamore has the smallest crown diameter. It would seem that the crowns of dominating trees are more efficient in utilizing space. A larger number of trees can, therefore, be grown per 1 ha on the uppermost level of the canopy.

The correlation between size and density has been the subject of serious research for decades (Pretzsch, 2005). As of yet pinpointing the exact correlation in the sycamore has proven impossible. Tentative results have been obtained in France that compare the curves of self-thinning of the sycamore, European beech, European ash, sessile oak, and common oak: there is scarce data on the sycamore but the correlation between size and density suggests that there is a steeper curve in comparison with the European beech (Le Goff, Ottorini, 1999) and the European ash, but similar to that of the oaks. A pure, equal-age sycamore stand will therefore have lower density than a pure stand of European beech or European ash, and the same density as a sessile oak or a common oak stand.

The identification of the sycamore stand reserve in Bulgaria is carried out based on growth tables for common beech according to Nedyalkov (1960), Duhovnikov et al. (1963) (Krastanov, Raykov, 2004). Such is the recommendation of Marschall (1975) for Austria. European ash tables are used in Germany instead (Hein et al., 2009). Hamilton, Christie (1971) suggest common tables for calculating the sycamore, ash and birch stand reserve in the UK. To calculate the reserve in stands and crops in Romania Giurgiu (1974) proposes the equation:

$V=a\cdot 10^{(b\cdot \log(D)+c\cdot \log(D)^\wedge 2+d\cdot \log(H)+e\cdot \log(H)^\wedge 2)}$,

Where H is the mean height, D – the mean diameter of the stand, and the values and a=0.00035375; b=1.02; c=0.3997; d=0.666; e=0.021.

Hein et al., (2009) point out significant regional fluctuation in the growth rate of the sycamore. According to Kjølby (1958), in Denmark the current increase in stock peaks at the age of 21 – 19.5 m3.ha-1, and is average at the age of 27 – 15 m3.ha-1 for Class 1 stands. The reserve of 80 years reaches from 700 $m^3.ha^{-1}$ (Class 5) to 1050 $m^3.ha^{-1}$ (Class 1). The current increase for Germany peaks around the age of 20 (approximately 20 $m^3.ha^{-1}$) and the average on – about the age of 30 (15 $m^3.ha^{-1}$) (Spiecker, 1991).

The stand reserve is affected by the intensity of thinning. There are limited results for the sycamore. In experimental trial grounds in Denmark, intensive thinning between the ages of 17 and 44 (Jensen, 1983; Bryndum, Henriksen, 1988; Henriksen, Bryndum, 1989; Jorgenensen, 1992; Plauborg, 2004), leading to a reduction of the circular area to 60%, has resulted in a drop in the volume increase with over 10%, and in a circular area reduction of 30% – the current rise of stock has dropped to 60% compared to непрореждаником controlled checks. The diameter growth of dominating trees is barely (or not at all) affected by these thinning. This conclusion is in conflict with Stern's (1989) claims that the sycamore is able to react positively to late growth felling compared to species such as the common cherry tree or ash trees. The possible inaccuracy in Stern's (1989) claim is further supported by the fact that the sycamore reaches an early peak in height and diameter growth, which is a good indicator of the crown's capability to react to thinning (Hein et al., 2009).

A number of studies show that at the age of 80 sycamore productivity (~ 1050 $m^3.ha^{-1}$) is higher than that of European ash (555 $m^3.ha^{-1}$) and common beech (546 $m^3.ha^{-1}$). This is why the European ash cannot serve as an alternative to conditions that suit the sycamore tree. The information comparing it to the common beech, however, is inconsistent. There are data that the common beech can have a larger reserve than the sycamore after the age of 40 (Henriksen, Bryndum, 1989; Schober, 1995; Lockow, 2004; Hein et al., 2009).

Forestry activities for growing high quality timber

There are many recommendations for the growing and management of sycamore in Europe. Although they often give good results in local forestry practices, they are based on statements and hypotheses without being objectively studied. Therefore, their application in a wider geographical area should be tested (Kerr, Evans, 1993; Armand, 1995; Bartoli, Dall'Armi, 1996; Joyce et al., 1998; Tillisch, 2001; Hein et al., 2009).

Various studies have focused on the self-pruning abilities of the sycamore under various habitat conditions and stand compositions (Nutto, 1999; Hein, 2008; Makinen et al., 2003; Hein et al., 2006; Hein et al., 2009). The studies on the effect of artificial pruning of the species are limited (Hubert, Courraud, 1987; Joyce et al., 1998; Boulet-Gercourt, 2000; Hein, Spiecker, 2007; Hein, 2008).

Despite the industry's demand for high quality, large diameter timber, there only exists a limited set of qualitative forestry instructions and practices on how to achieve these parameters (Hein et al., 2009). Europe's approaches to these aspects vary considerably between authors (Thies et al., 2008), especially with regard to the final number of trees of the future. Hein (2004) and Hein, Spiecker (2008a) suggest a model framework for quantitative silvicultural purposes for the sycamore tree. They recommend the preservation of 72 dominant target trees per 1 ha with a diameter of 60 cm, with a felling cycle of 75 years; at the age of 60 the length of the self-pruning section should reach 11.8 m.

Although models currently exist, many recommendations for silvicultural practices remain unclear quantitatively (Joyce et al., 1998). There are still no studies on the continuity between these silvicultural objectives that head in two directions – growing a limited number of target trees on the one hand, and achieving maximum plant productivity on the other (Spiecker, 1991; Kerr, 1996). Furthermore, there is still a debate on the appropriate time to select target trees: if it is done early, the crown will react very quickly to the growing activities, but the length of the clear section will be shorter than if this choice is made at a later stage. Ultimately, the criteria for selecting target trees are generally established and can be ranked according to their priority: vitality, quality and location. Quantitative information on minimum survival rate, acceptable levels of trunk loss, and their dynamics over the years is not yet available (Hein et al., 2009).

Three approaches to cultivation of the stands have been identified in the literature (Hein et al., 2009).

The first approach is based on growth clear-cutting on the basis of the optimal number of trees per 1 ha. This approach, however, fails to take into account the growth reaction that follows higher intensity growth clear-cutting, as well as extreme climate conditions and their effect on the stands. In addition, this approach can be applied to mixed stands with a group-mosaic mixture.

The second approach is based on the average distance between neighboring trees in the target group. It was proposed by Spiecker (1994) for the common cherry, by Armand (1995) for the European ash and by Hein, Spiecker (2008a) for the sycamore. It is considered that the average radial growth of 4-5 mm per year should be ensured through the growth activities. The recommendation stems from the relationship between crown width, the 1.30 m diameter at 70% crown closure, and a constant (22), which multiplies the trunk diameter (in m) to obtain the required radius around the target tree, in which cultivation is to be carried out. For example, for a target tree with a diameter of 30 cm (0.3 m), the diameter must be multiplied by the constant 22. The result shows the required distance (in m) between the specimen and its closest competitor, in order to achieve and maintain an increase in diameter of 4-5 mm. In this case, all competitors within a circular radius of 6,6m would have to be removed. The frequency of growth clear-cutting depend on the time needed for closing the canopy between the target tree and the neighboring tree.

The third approach recommends the type of clearcutting that aims to remove the competition between crowns upon reaching a specific length at the base of the self-pruned section. This approach is known as the two-step controlled growth concept (Spiecker, 1991; Wilhelm, Raffel, 1993; Wilhelm et al., 1999) for deciduous species and (Hein, Spiecker, 2008a) for the sycamore. The first phase covers the formation of the stand until the desired length of self-pruning of the trunk is reached ("free" of wood clumps). Emphasis in management during this phase is given to natural self-pruning. It is called the rearing phase. Only a few silvicultural interventions are needed to maintain the required species composition and the removal of poor quality trees when competing with target trees.

Once the self-pruning trunk section reaches the required height, the trees of the future are marked and the second phase begins. In case the self-pruning is insufficient, the branches can be pruned before they reach a diameter of 3 cm at the base. All interventions during the second phase are aimed at supporting the increase in diameter to reach the desired size. It is not necessary to ensure future competition of the crowns, as the target trees are grown selectively and with great intensity. This system contributes to the maintenance of a sufficiently self-pruned trunk (Hein et al., 2009).

Hein et al. (2009) conclude that even though the sycamore is an attractive species for forestry, there is a lack of science-based research on its cultivation. This prevents foresters from improving the applied silvicultural strategies and making them applicable at the local level. Although there are materials in some national, non-peer-reviewed publications, this does not make up for the need for scientifically sound argumentation. Filling the information gaps in the growth of the common maple can contribute to improving the management of forests in our country and in Europe.

Conclusion

The ecologically optimal conditions for the sycamore include a cool and humid mid-mountain climate, and rich, well-stocked in moisture soils. In such habitats it can achieve productivity that meets the requirements for intensive crops.

For **seed propagation**, seeds should be stored in a dry environment at a temperature of 4°C, with the goal of preserving their initial humidity and cold stratification for 1 month before sowing in the spring.

For **enrooting cuttings**, a successful result is obtained by shading the donor before the beginning of the vegetation to obtain etiolated shoots with one node; in the beginning of May treatment of the base node with IBA paste (based on Vaseline or lanolin) with a concentration of 8000 $mg.l^{-1}$ and protection with aluminum foil; parallel uncovering of donors for deetiolation for 4 weeks before planting. Rooting reaches 72%.

For sycamore **grafting**, it is recommended to rely on spring and summer grafting by copulation. The successful intergrowth of the components reaches 93.33%.

Sycamore crops can be made pure or mixed in composition. Suitable mixing species are: Norway maple, silver linden, field maple, common cherry, European ash.

For the **production of high-quality, large-sized timber** from sycamore, cultivation using the high-quality wood production method (Saarland method) can be applied. The approach can be tentatively divided into two stages – until the formation of the desired self-trimmed part of the trunk length, approximately 25% of the potential height in adulthood, and phase two – ensuring optimal diameter growth of the “trees of the future.” The first stage covers the phases of emergence and differentiation, during which the aim is to ensure sycamore trees participate in the mixed stands, as they are selected as “option trees” and their main competitors are broken or girdled. The second stage involves growing the “trees of the future” by cutting down all their crown area competition.

The issues considered for propagation and cultivation of the plantations can help to optimize the future work with sycamore trees in Bulgaria.

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