A review on the ecology and silviculture of limes (*Tilia cordata* Mill., *Tilia platyphyllos* Scop. and *Tilia tomentosa* Moench.) in Europe.

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A review on the ecology and silviculture of limes (*Tilia cordata* Mill., *Tilia platyphyllos* Scop. and *Tilia tomentosa* Moench.) in Europe.

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Abstract

*Tilia (*lime*)* is a genus in the family of *Tiliaceae* with about thirty species of trees, native throughout most of the temperate Northern Hemisphere, in Asia, Europe and eastern North America; it is absent in western North America. Lime trees grow on rich soils, mesotrophic or mesoeutrophic, fresh or moderately moist, with mull or moder humus. Such soils have neutral or alkaline pH soil reaction. Lime prefers sites with higher calcium content.

Lime regenerates naturally under the stand canopy during the shelterwood cuttings on rich sites. In Poland lime regeneration is successfull. Although *Tilia cordata* regenerates freely in groups in Białowieża Forest, vegetative reproduction is very important for populations growing on the border of natural range. This ability is a part of a life strategy that allows the possibility of outnumbering other species. Thus producing sprouts prolongs the life of *Tilia* trees, even after damage to old stumps. Lime is palatable therefore in stands heavily populated with deer, they are continuously subjected to extreme browsing damage and repeated barking. Lime can be found as co-dominant tree species in mixed stands as a result of its vitality and adaptation to the changing environment. Pure stands can be found in the eastern part of Europe (i.e. lime or lime-oak forests in Russia). Depending on ecological conditions and geographical location lime species can be mixed with other broadleaved tree species such as beech, oak, maple, hornbeam, as well as coniferous species such as Norway spruce, Scots pine, yew and silver fir. In wetter sites lime trees can grow in mixture with elm, ash and black alder. Compared to beech trees, lime grows quicker in the first 50 years of life, but by the age of 100 years beech stands yield about 30 % more than lime stands. Yield tables for *Tilia* species are rare and those available for *Tilia cordata* in Germany show that the growth shape and patterns of *Tilia* are totally different to those for beech stands. For these reasons the current use of beech yield and volume tables for the management of lime stands should be avoided. The early growth culmination as well as the quality development of lime stands

requires the application of selective thinning in younger stands and moderate thinning in older stands. Only a few scientifically based studies concerning *Tilia* species are available. Forest managers tend to treat these species either according to their own experience or by using data available for other broadleaved species. Further research on the growth of *Tilia* species will enhance their sustainable forest management in Europe.

Keywords: *Tilia* sp, broadleaves silviculture, regeneration, wood quality

Introduction

Tilia is a genus in the family of *Tiliaceae* with about thirty species of trees, native throughout most of the temperate Northern Hemisphere (10), in Asia, Europe and eastern North America; it is absent in western North America. Only four of these species occur naturally in Europe, i.e. Caucasian lime *Tilia dasystyla* (Stev.), silver lime *Tilia tomentosa* (Moench.), small-leaved lime *Tilia cordata* (Mill.) and large-leaved lime *Tilia platyphyllos* (Scop.). The latter two species cover almost the whole continent of Europe except for large parts of Scandinavia. The third species, *T. tomentosa* (Moench.), grows only in the Balkans, especially in the former Yugoslavia, Bulgaria, Romania and Greece. *T. cordata* and *T. platyphyllos* form natural inter-specific hybrids when individuals of these species exist in the close proximity; these forms are known as “common linden” *Tilia x europaea* (L.) syn. *Tilia x vulgaris* (Hayne) (Mauer and Tabel, 1995).

The objective of this review is to synthesise the existing knowledge on different aspects of the growth of lime which are relevant to the silvicultural practice. We intend to describe the establishment and growth pattern of lime trees, to identify the various factors that may control their variability and to provide conclusions for forest management. Emphasis will be given to the specific problems of growing lime in mixture with other species. Within these objectives the paper is starts with the biological characteristics of species followed by conclusions and recommendations for forest management.

Distribution area

Despite their enormous importance in the history of Europe and in particular of German civilization (Boratyńska and Dolatowski, 1991), indigenous lime species have become extremely rare as forest trees.

Exploitation of beech during the last two centuries is considered to be the main reason for the decline in the occurrence of lime in woodlands. (Boratyńska and Dolatowski 1991). However, due to their specific biological and ecological properties (e.g., regeneration by stump/root sprouting, almost annual fructification, maintenance of soil fertility by the rapid decomposition of litter foliage, shade tolerance), there has been an increasing interest in the domestic lime tree by both tree breeders and silviculturists over the past 30-40 years.

The distribution of *T. cordata* is strongly correlated with the temperature of north Europe – annual isotherm of + 2 ºC and July isotherm of + 17 ºC (Boratyńska and Dolatowski, 1991; Piggot and Huntley, 1978, 1980). Its distribution is suboceanic to subcontinental and it is most abundant from north-east France through central Germany and Poland to central Russia and north Ukraine. It is common in the Swiss plain and the lowland parts of Austria, Czech Republic and western Hungary, occurs sparsely in the Alps valleys and is absent in the dry parts of the Hungarian plain. The majority of the southern most localities are at altitudes above 200 m and on north-facing slopes or cliffs (Barna, 1996). It is almost certainly summer drought which determines the southern limit of *T. cordata* in the Mediterranean region.

In Italy the genus *Tilia* is represented by the species *Tilia platyphyllos, Tilia cordata* and their hybrid. *Tilia* stands in Italy are rather rare, found in warm and wet sites with an abundance of nutrients. *Tilia* re-enters the group of “noble broadleaves” together with maples, elms, ashes and walnuts because of its good wood quality (Bernabei and Pollini, 2006).

T. platyphyllos occurs in central and south Europe. The northern limit is found in north Belgium, central Germany, south Poland and west Ukraine. It also grows in Denmark and south Scandinavia. In the south of Europe it occurs in the Mediterranean region, with the exception of the Iberian Peninsula. The species grows in the lowlands and foothills of mountain regions as an auxiliary tree in mixtures with other broadleaved tree species up to an elevation of 1,800 m a.s.l. in the Alps (Boratyńska and Dolatowski, 1991). *T. platyphyllos* is frequently planted as an ornamental tree in parks and as a shade or lawn tree. It has been introduced in the U.S.A. (New England).

T. tomentosa grows in Romania, where the species reaches the northern most limit of its European range (on southern and western slopes) up to 1,000 m elevation as in the south of the country. The optimum elevation of silver lime stands in Romania is 150-450 m (Haralamb, 1967; Stanescu et al., 1997).

In Bulgaria *T. tomentosa* grows in the north-eastern part and is found in the flat hills and foothill of the Mizian zone. The species covers 17,273.1 ha of which 13.3 % are pure stands, with dominance of *Tilia* above 5% in 56.7% of the area, and below 5% in 10% of the area. Soil moisture is the factor, which restricts the natural occurrence of *T. tomentosa.* In conditions over the age of 50 – 60 years silver lime dominates over steep and flat terrains replacing progressively *Carpinus betulus, Quercus ceris, Fraxinus ornus* and *Acer campestre* to form initially pure spots and finally pure stands (Kalmukov, 1984; Tsakov, 2007).

In Greece, *T. cordata, T. platyphyllo*s and *T. tometosa* are found in the vegetation zones of deciduous broadleaves in mixture with beech, oak, ash, and maples; pure stands are very rare. Its distribution is scattered from the Parnon Mountain (Peloponnese) up to Rodope (north Greece) at altitudes of up to 1,200 m a.s.l. In former times lime trees were more abundant in the Greek mountains. Nowadays they are rare because of competition with other broadleaved species in coppice forests, the intensive pruning for lime flowers and heavy livestock grazing (Basiotis, 1972).

Site requirements

Lime trees grow on rich, mesotrophic or mesoeutrophic soil, fresh or moderately moist, with mull or moder humus. Such soils have neutral or alkaline soil reaction. Lime prefers sites with higher calcium content (Jaworski, 1995). *T. cordata* grows naturally on a wide range of soil types from podzols through brown podzolic soils, brown earths and brown calcareous earths to rendzinas. It can be found on soils with a wide range of textures: from soils with a high proportion of clay and silt to those containing mainly sand or a high proportion of pebbles, as well as on screes and block screes.

T. cordata has a wider range of soil moisture tolerance than *T. platyphyllos* (Ellenberg 1996; Rameau et al., 1989; Basiotis, 1972). It can grow on soils with a shallow ground water table.

T. tomentosa requires fertile, deep, low-acid or neutral (pH 6.2-7.2) mineral soils, developed on sand-loam/loam-clay (optimum loam). It definitely avoids argillic or pseudogley soils found on plateaus or flooded areas. For a given soil moisture *T. tomentosa* seedlings grow higher (40-47%) in height on leached chernozem and dark grey soils than on carbonate chernozem. The use of silver lime for intensive timber production plantations on sites with calcium carbonate concentrations in surface horizon higher than 1.5% is not advisable (Kalmukov, 1984).

Regeneration and early growth

Shade-drought tolerance

Lime, ash, oak, elm and pine are all '*post-pioneer'* species according to the dynamic classification of trees (Rameau et al. 1989). Based on foresters' experience and general observations, *T. cordata* is generally considered as a shade tolerant species (Pigott, 1991). Some authors such as Dengler (1971, referenced in Pigott, 1991) classified *T. cordata* as very shade tolerant.Others (Ellenberg, 1978) it as moderately tolerant, less tolerant than *Carpinus betulus* and *Fagus sylvatica* and more tolerant than *Quercus petraea* and *Betula pendula*. Basiotis (1972) classifies lime trees in Greece as semi- shade tolerant in the young stages and shade intolerant (light demanding) species later; owing to their rich foliage they are considered as soil-improving species.

Russian authors consider small-leaved lime as shade tolerant, being able to survive even beneath the canopy of *Picea abies* (Pigott, 1991). Although lime seedlings and saplings are able to survive under dense shade, their growth in the third and fourth years needs more light for a successful regeneration (Pigott, 1991). Koss and Fricke (1982) reported that when more light penetrates the canopy understorey lime trees show a strong increase in height growth. The lime trees also grow steadily and vigorously under a closed (over 100 per cent stocking) overstorey. As shade increases the radial growth of lime trees decreases much more than the height growth. With increasing breast height diameter (dbh) the proportion of long shafted lime trees increases significantly along with a great reduction in forked stems. The proportion of lime trees with upward directed branches also increases while the weaker trees form horizontal branching in order to compensate for the light deficiency.

Piggot (1975) in his study on natural regeneration of *T. cordata* in Białowieża Forest reported that small-leaved lime regenerates freely with numerous groups of seedlings, saplings and young trees found not only in gaps but often beneath the main canopy. *T. cordata* can establish and continue to grow slowly in situations where the daily irradiance is 200-300 kJ m^{-2} in August, so that its establishment is unlikely to depend only on existing gaps in the canopy. The shade tolerance of small-leaved lime when young, the large size of mature trees as well as their longevity suggest that the species is potentially the dominant one within this type of forest.

T. platyphyllos tolerates temperature as low as -3 to -8 ºC, and *T. cordata* from -7 to -16 ºC (Korotaev, 1994) with an upper limit of 44 ºC. It is susceptible to flood, especially stagnant water (Lyr, 1993). Lime species, especially *T. platyphyllos*, are resistant to drought, dry winds and low temperatures; they are suitable for commercial and protective planting (Biryukov, 1991). The drought sensitivity of European trees increases roughly in the following sequence: ash *(Fraxinus* sp), oak (*Quercus* sp), rowan (*Sorbu*s sp), lime (*T. cordata* > *T. platyphyllos*), pine (*Pinus* sp).

Lime species appear to be salt-sensitive compared with other species such as *Robinia, Quercus, Populus, Eleagnus*, however inoculation with mycorrhiza can considerably increase salt tolerance to a level comparable with more salt-tolerant tree species such as *Populus canescens* and *Ulmus x hollandica* (Weissenhorn, 2002).

Vegetative reproduction

Vegetative reproduction is more frequent than generation from seed. About 77-80 % of young trees in the south-west stands of Russia and almost 100 % in the north-east of European are the result of vegetative reproduction (Cistyakova, 1979, 1982).

T. cordata has a remarkable capacity for vegetative reproduction (Biehler, 1922; Sokołowski, 1930; Suchecki, 1947). This ability is part of a life strategy which gives it the possibility to outnumber other species. About 90 % of old lime trees in Białowieża National Park sprout from the root collar (Faliński, 1986; Pawlaczyk, 1991).

Vegetative reproduction is very important for populations growing on the border of its natural range. Lime populations in north-west England (Piggot and Huntley, 1981, Piggot, 1989), in Finland (Korczyk, 1980) and Siberia (Polozij and Krapivkina, 1985) exist due to this phenomenon.

Lime trees sprout strongly after cut and show no decline in sprouting vigour with age (Pigott, 1991). Sprouts can develop from both cut and fallen stems even in old age (over 200 years old or, in some special cases, over 300 years old) (Pigott, 1989). Branches touching the ground may become rooted producing vertical shoots. The other example of vegetative reproduction is the ability to create layering of shoots (Murachtanov, 1972; Piggot and Huntley, 1981; Piggot, 1989).

The sprouting ability of lime trees tends to decline with age. Where coppicing has been practised regularly the ever enlarging stump can be maintained for many hundreds of years notably with *T. cordata* but also with other tree species such as ash, field maple, sweet chestnut (Evans, 1984).

Sprouts can develop from dormant buds located in the root collar of parent tree with root suckers found up to 5 m away from the parent tree. Young sprouts (especially 1-1.5 m height) are subjected to snow, mechanical, pathogens (*Nectria cinnaberina*), and browsing damage. Winter browsing can stop the growth of sprouts. Such situations were seen in Białowieża National Park before the First World War (Faliński, 1986). In favourable conditions many sprouts (as many as 20-30 individuals) can be found around the mother tree. The consequences of sprout production are prolonged life, even after damage to the old stump and prolonged fruiting time. This behaviour known as "strategy of persistence" is very important for limes. This is especially so because of their low resistance to pathogens (Faliński and Pawlaczyk, 1991).

Spethmann (1982), in his study on cuttings propagation of broadleaved species, found the optimal date for inserting ramets into propagation trays for *T. cordata* is May and June, with lime appearing to be more date-dependent compared with beech, birch and oak which are more hormone-dependent species. Becker (1980) who reports a rooting rate of 70 % and satisfactory rooting system in small-leaved lime cuttings planted during the second fortnight of June also confirmed this finding.

Generative reproduction

The generative reproduction depends on many factors. Near the borders of limes natural range, enough seed production for seed collection or establishment of natural regeneration can be expected only in above-average warm summers. *T. cordata* is self-fertile but possesses efficient sterility mechanisms in competition with the foreign pollen (Fromm, 2001).

Flowering and seed production of stand trees begins at the age of about 25-30 years, but trees originating from sprouts blossom 10-15 years earlier (Tyszkiewicz and Obmiński, 1963; Pospisil, 1975). *T. cordata* and *T. platyphyllos* flower in July (Barzdajn, 1991) and produce seeds almost yearly (Murakhtanov, 1981). One million seeds/ha are produced during mast years, 500,000-700,000 seed/ha in medium years and 150,000-300,000 seed/ha in poor years (Murakhtanov, 1981). Light, drought and frost are very important factors for flower development. Piggot, 1975, reprted that if temperatures fall below 12 ºC. ,pollen tube growth is inhibited.

Most seeds falls in autumn but some is retained on the tree and then fall with snow. The phenomenon of seed propagation has an important effect on lime ecology. Seeds staying on twigs has a different physiological propertie to seeds falling in autumn. Seeds lying on snow can be wind-distributed over much larger distances (few hundred meters).

Lime regenerates naturally under the stand canopy during the shelterwood cuttings on rich sites. This has been successfully demonstated in Poland (Piggot, 1975; Kowalski, 1982). However, in the opinion of Russian scientists, natural regeneration of lime is rather seldom (Cistyakova, 1982; Polozij and Krapivkina, 1985).

Lime can be planted on poor sites. 1-year-old (seldom 2 or 3-year-old) seedlings are planted individually or in groups with an area of 0.5 ha. On rich sites lime should play the role of co-dominant tree especially in oak stands. It is planted at 1.2x1.2 m to 2.2x2.2 m spacing (Jaworski, 1995) simultaneously with oak, or under its canopy.

Lime belongs to trees of moderate attraction for animals' diet. In stand heavily populated with deer, lime is continuously subjected to high browsing damage and repeated barking (Trauboth, 2005). In Sweden depending on the species, between 19 and 85 % of the seedlings were browsed after one winter. When the deer population was eliminated, the young lime stands were able to establish themselves in some area of Bialowieża Forest (Faliński and Pawlaczyk, 1991). The following descending sequence, based on the number of browsed seedlings, was considered: *Quercus robur* > *Alnus glutinosa* > *Fagus sylvatica* > *Tilia cordata* > *Prunus avium* > *Betula pendula* > *Picea abies* > *Fraxinus excelsior*. The leader was damaged on 83 % of the browsed seedlings (Kullberg and Bergstörm, 2001).

Some parts of lime trees are very important for animals' diet. Roots, bark, sapwood, leaves, fruit, seeds and shoots are eaten by 21 species of mammals. Jensen (1985) found that seeds are preferred by mice and voles, which can eat 30-95 % of seeds lying on the forest floor. However, the behaviour of moles – digging and collecting seeds – can favour natural regeneration of lime.

Growth and Yield

Both *T. cordata* and *T. platyphyllos* grow slowly in height at young ages with *T. platyphyllos* growing quicker than *T. cordata*. Their height can be about 3.5 m at 11 years of age (table 1). Lime trees can reach 35 (40) m in height and 100-300 cm in diameter. Their longevity can be up to 1,000 years (Mayer, 1977). Koop (1989) showed the growth of lime trees as follows: 400 year-old tree: 85 cm dbh; 75 year-old tree: 25 cm dbh; 50 year-old tree:

15 cm dbh. In Białowieża National Park (multi-layered stands) lime trees can reach 42 m height and 2 m dbh at the age of 300-350 years (Faliński, 1977; Tomanek, 1986). Up to the age of 50 lime trees grow quicker than beech trees. At the age of 100 years beech stands yield more (about 30 %) than lime stands. The volume of such lime stands is about 300 m^3/ha (Mayer, 1977; Navmar and Spethmann, 1986)

Growth and yield for *T. cordata* in Germany was summarized in a yield table compiled by Böckmann (1990) and based on volume functions by Böckmann and Kramer (1989), Röös and Böckmann (1989). Böckmann's yield table showed that the growth shape and patterns of lime and beech stands are totally different and the beech yield and volume tables used so far for lime stands are not suitable for management purposes. On good sites lime stands shows reasonable volume and quality production which are higher than those of beech. The early growth culmination as well as the quality development of lime stands requires the application of selective thinning in younger stands and moderate thinning in older stands. *T. cordata* reaches 35-40 m in height on good sites and develops branch-free stems in fully-stocked stands. Stem quality is best in very dense stands, where the percentage of forking is reduced (Rossi, 1993).

In the Obrożyska reserve the *T. cordata* stands have one of the greatest volumes (761-861 m^3/ha) among stands of primeval character in the Polish side of the Carpathians. The largest lime trees reached 110 cm dbh and 35.5 m height. Basal area of lime was also very high (55-62 m^2/ha) and greater than that of beech, fir and spruce (Jaworski et al., 2005).

T. tomentosa grows quickly in height when young especially if regenerated from stump stools and root suckers. At the age of 10 years such trees can be as tall as 4.3-7.8 m (Haralamb, 1967). The maximum height increment is reached at the age of 10-15 years after which the height growth slows. The height (mean and dominant) of pure silver lime stands regenerated by seeds reaches the dimensions of 17.6 m to 30.5 m and 19.9 to 31.8 m respectively (Haralamb, 1967).

Kalmukov (1987), in his study on growth and productivity of natural stands of *T. tomentosa*, reported that stems were self-pruned and free of branches after the age of 45 years in stands ranging between 20 and 90 years old. The branchless part of the log reached 11-13 m long. Maximum growth in term of height occurs before the age of 9-10 years. By the age of 90 years the culmination of the mean and current increment in volume hasn't yet occurred. The standing volume of *T. tomentosa* stands at the age of 70 years ranged from 308 to 517 m^3/ha. The mean volume increment at the same age ranged from 4.0 to 10.2 m^3/year/ha.

Dimitrov, (1996) calibrated a multifactor model which can predict the number of sprouts per ha of T. *tomentosa* coppice stands from variable such as coefficient of density, breast height diameter and height. The model was based on 510 sample stems collected from pure and mixed coppice silver lime stands of different age and grades.

The normally emergent crown of *T. cordata* is hemispherical and reaches 5-12 m in diameter. However when lime trees grow in an open environment without any competition their crowns can reach 20 m diameter, usually branch-free 2-4 m from the ground. At the age of 300-400 years the lime trees develop a massive trunk of 1.5-2.0 m diameter with irregular buttresses and many horizontal ascending and vertical branches which together form a parabolic crown. Lower branches of the former are horizontal and arch-like; whilst branches of the later and upper branches are horizontal, ascending or vertical (Pigott, 1991).

Under the influence of some factors *Tilia* individuals can develop the "shrub shape". Silvertown (1987) called these phenomena "Oskar's syndrome" or "waiting strategy". It is still unknown how long the Oskar's juveniles can grow. However, the maximum age of the quasi-senile individuals is many tens of years (Belostokov, 1980; Smirnova et al., 1984). The possibility to develop the "shrub shape" under unfavourable environmental conditions and the ability of vegetative reproduction are limes' life strategy and ecological plasticity.

Trauboth (2005), comparing the growth of lime in pure and mixed stands (with beech, oak, fir, and larch), found that lime was superior to the other species in all cases. In 20-35-year old stands, with an appropriate density of lime trees, such individuals of 15-17 cm dbh reached branch-free boles ranging between 4 and 7 m height.

The biological rotation age of *T. tomentosa* varies between 150 and 200 years. The technical rotation age of pure silver lime stands depends on the production target as well as the function that the stand provides (Table 2). The diameter increment of the same kind of stands shows the same pattern but reaches its maximum (4.0 cm) later on - between 20 and 30 years. The volume increment reaches its maximum (11.2 m^3/ha/yr) at 35-40 years of age. The maximum volume increment of total production depends on yield class. The mean volume increment of pure *T. tomentosa* stands regenerated by seeds ranges from 7.7 (m^3/ha/yr) in the I^{st} yield class to 3.0 (m^3/ha/yr) in the V^{th} yield class. Based on this high volume increment, the yield of pure silver lime stands regenerated by seeds is also quite high as shown in Table 3 (Giurgiu and Draghiciu, 2004).

Lime in mixed stands

Lime can be found as co-dominant tree species in mixed stand forest as a result of its vitality and adaptation to the changing environment, this is especially due to its "waiting" and "persisting strategy". An increase in the proportion *T. cordata* in mixed stands from the south-west to north-east is observed in Europe. Because of the rapid decomposition of lime leaves this species can play a positive role in forest development on relatively poor sites (Maes and van Vuure, 1989; Hommel and De Waal, 2003). Pure stands can be found in the eastern part of Europe (i.e. lime or lime-oak forests in Russia). Depending on ecological conditions and geographical location lime species can be mixed either with other broadleaved tree species such as beech (*Fagus sylvatica*), oaks (*Quercus robur* and *Q. petraea, Q. pubescens*), maples (*Acer pseudoplatanus*, *A. platanoides*, *A. campestre*), hornbeams (*Carpinus betulus* and *C. orientalis*), *Ostrya carpinifolia*, as well as coniferous species such as Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), yew (*Taxus baccata*) and silver fir (*Abies alba*). In wetter sites lime trees grow with elms (*Ulmus* sp*)*, ash (*Fraxinus* sp*)* and black alder (*Alnus glutinosa*). Small-seeded trees such as aspen (*Populus tremula)*, goat willow (*Salix caprea*), birches (*Betula pendula* and *B. pubescens*) and alder (*Alnus* sp) are introduced to the forests as a results of anthropogenic pressure. Lime grows in many different communities as *Molinio arundinaceae-Quercetum*, *Potentillo albae-Quercetum* (Matuszkiewicz, 2001) or *Tilio-carpinetum typicum* (Sokołowski, 1930).

T. platyphyllos occurs especially in beech and maple-lime (*Aceri-Tilietum*) forests in Poland. In other countries it grows together with sycamore and ash (*Phylitidi-Acerum* and *Arunco-Aceretum, Acero-Fraxinetum*) or with yew and beech (*Taxo-Fagetum*) (Oberdorfer, 1957, 1962; Rameau et al., 1989).

T. tomentosa is a medium intolerant and climax species, found in even age stands of either pure lime (as in the south-east of Romania) or in mixed stands with other broadleaved tree species such as *Quercus robur*, *Carpinus betulus*, *Ulmus campestris*, *Acer campestris*, etc. It is also found in mixed stands of forest steppe along with *Q. pubescens*, *Fraxinus ornus*, etc. It can thrive on relatively compact soils such as those found on terraces, where it grows in mixtures with *Q. cerris*, *Q. frainetto* or even *Q. pubescens* (Stanescu et al., 1997).

Lime wood quality aspects

The wood of lime species is light coloured and straight grained with a smooth uniform texture. Because of its colour, even grain and easiness of working, it has been used to manufacture boxes and crates, for wood turning, furniture, trunks, venetian blinds, picture frames, carriage bodies, beehives, plywood, cooperage, pulp, and charcoal. In Greece lime wood is used for temple carving in Orthodox churches as well as in turnery. Other uses include children toys, carving and crafts making, pencils, tennis rackets, beehives and, musical instruments (Tsoumis, 2002).

The flowers, leaves, wood, and lime charcoal are used for medicinal purposes. Lime-flower tea has a pleasant taste, due to the aromatic volatile oil found in the flowers. Active ingredients in the lime flowers include flavonoids (which act as antioxidants), volatile oils, and mucilaginous constituents (which soothe and reduce inflammation). The plant also contains tannins that can act as an astringent (Bradley, 1992).

Silviculture

Lime is an auxiliary tree species that plays a very important role in oak plantations. It shades oak stems, influences soils, prevents dense plant vegetation and accelerates litter decomposition. Epicormic shoots do not occur on oak trunks when mixed with lime. Lime can be planted simultaneously with oak or under oak canopies after thinning. During thinning in a well developed layer of *Tilia* only one oak tree is left at each opening. *T. platyphyllos* exhibited the best growth and stem form (average branch-free height, due to self-pruning, of 5.5 m) under the oak canopy (Fricke et al., 1980).

Evans (1984), reviewing the coppice history in Britain, considers that both short- and long-rotation coppicing can be traced back to Neolithic times (4.000 BC). In coppice with standards, *Tilia* trees form the underwood whilst other tree species (standards) produce larger size timber. This silvicultural system was very widely used and the legally required way of managing coppice during the reign of king Henry the VIIIth of England.

In Greek mixed broadleaved coppice forests that are converted towards high forests, lime trees as well as other valuable broadleaved species are protected. Their inclusion in mixtures is favoured by silvicultural treatments because of their soil-improving abilities, better site utilization and landscape aesthetics (Dafis, 1966; Basiotis, 1972).

When considering the needs for tending interventions, some aspects related to *T. tomentosa* should be taken into account:

- it is a fast-growing and vigorous species;
- it produces stump sprouts and root suckers abundantly;
- in terms of light requirements it is moderately shade tolerant;
- if its stem is exposed to direct sun light (sudden crown release) it produces epicormic branches and can be scorched by the sun

Based on these facts the silvicultural interventions proposed to *T. tomentosa* pure stands regenerated by seeds in Romania are as follows (MAPPM/1, 2000):

1. **Weeding (w)**. The main purpose is to protect the silver lime trees of seed origin over those regenerated by sprouts or suckers. Rotation of weeding is 1-3 years and canopy closure is maintained at a minimum of 80 % after intervention.
2. **Cleaning-respacing (c-r)**. In stands where the weeding was performed. The first cleaning-respacing is performed at a stand age of 10-12 years. As in the case of the following interventions the first focuses especially on the upper storey of the stand to eliminate non-desirable species, defective trees, etc. After c-r intervention the canopy closure is at least 80 % as in the case of weeding. Rotation of c-r is 4-6 years depending on the yield class of the stand: 4 yearly in high production stands (yield classes I and II), 6 yearly in low production stands (yield classes IV and V).
3. **Thinnings (t)**. Starts age 20-25 years and target the spacing of future crop trees. The intensity of thinning is moderate (decreases constantly from 12 % of standing volume at 20-

30 years of age down to 6 % of standing volume at age 61-70 years) and the canopy closure after intervention is at least 80 %. Rotation of thinning increases from 5-6 years in pole stage to 8-10 years in high-forest stage. Thinning ceases at 55-60 years with the exception of silver lime stands targeted for the production of veneer logs. In this case the last thinning is applied at 60-70 years of age.

For *T. cordata* and *T. platyphyllos* cleaning is necessary 2-3 times per year. Early cleaning is first carried out 5 years after planting. The main objective of this is shaping forked trees. The rotation of cutting is 3-4 years and is performed 2 or 3 times. Late cleaning starts after 10 years, the main purpose being the removal of defect trees, and to shape the remaining trees. The rotation of late cleaning is 3-5 years and 2 or 3 treatments are usually performed. The first thinning is done at the age of 25, when the height of trees is about 10-12 m. The main objective is to select the potential crop trees. All defect trees are removed and the treatment is repeated with a 5-7 years rotation. The last thinning is performed at the age of 40 when the crown length is about 1/3 of total tree height. Normally 10-20 % of standing volume is cut during one intervention. The rotation of thinning is 8-10 years.

Lime trees especially *T. platyphyllos* and *T. cordata* are also important as ornamental trees and are frequently used by urban forestry in streets and parks. Flemming and Kristoffersen (2002) in their study on *Tilia*'s physical dimensions over time report that the average live span of urban trees is very short. The maximum dimensions that these trees reach are only 7 m in height at 20 years and about 20 m in height at 100 years while in natural environments these dimensions are 10 m and 40 m accordingly. The authors calibrated models that can be used for forecasting *Tilia's* physical dimensions as a function of time and environment. Such models can be also used for planning and assessing the consequences of *Tilia* tree-planting schemes in urban environments.

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Appendix

List of tables

Table 1. Height increment of <u>*T. cordata*</u> in Białowieża Primeval Forest (Kowalski, 1972).

Years	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
Height increment (cm)	12	23	26	25	24	20	16	10

Table 2.Technical rotation age of pure *T. tomentosa* stands (from MAPPM/2, 2000)

Production wood target	Technical rotation ages for stands providing…......functions (years)	
	Production	Protection
Sawlogs	50-80	70-100
Veneer logs	80-100	80-100

Table 3. Production of pure *T. tomentosa* remaining stand and total stand at different ages (Giurgiu and Draghiciu, 2004)

Age, years	Volume of *remaining stand* (m^3/ha) per yield class					*Total production* (remaining stand and removed stand), m^3/ha per yield class				
	I	II	III	IV	V	I	II	III	IV	V
50	415	354	294	236	179	652	555	456	362	270
60	459	398	332	270	209	757	650	540	435	332
70	496	431	362	298	233	848	733	614	500	387
80	527	459	390	320	253	930	807	680	557	435
90	553	483	411	339	270	1003	873	739	608	478
100	576	504	430	356	284	1069	933	792	655	517