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POTENTIAL OF *Tilia tomentosa* Moench, FOR USE IN URBAN ENVIRONMENTS IN NORTH-WEST EUROPE, BASED ON HABITAT STUDIES IN NORTH-EAST ROMANIA AND THE REPUBLIC OF MOLDOVA

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Abstract

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Trees are an important feature of the urban environment. In efforts to identify a greater diversity of species adapted to urban sites, dendroecological studies can help evaluate the reaction and tolerance of different tree species to stresses such as drought. This study examined the potential of silver lime (*Tilia tomentosa* Moench) for use as an urban tree in northern parts of Central Europe and adjacent, milder parts of Northern Europe (the CNE-region), based on habitat studies in north-east Romania and in the adjacent Republic of Moldavia. The data obtained in the field were compared with corresponding data from paved and park environments in urban Copenhagen. The results showed that silver lime trees in the natural habitats grew successfully in warmer and dryer conditions than those in park environments in Copenhagen, which indicates that this species also has potential for use at paved urban sites provided that water infiltration into planting pits can be enhanced.

Key words: dendroecology, habitat studies, park environments, urban paved environments

Introduction

Traditionally, a limited number of species and genera dominate the tree stock in streets and urban sites, and recent surveys in European and North American cities show that a few species/genera continue to dominate (Pauleit et al., 2002; Raupp et al., 2006; Bühler et al., 2007). Over the past few decades, however, a growing proportion of those commonly used species have shown increasing difficulties in coping with the conditions at urban sites. Impermeable surfacing, increasing storm water run-off and the urban heat island effect have resulted in tree decline and an increase in disease in urban tree habitats. This negative trend, combined with the challenges of climate change and the threat of further disease and pest attacks in the future (e.g. Sun, 1992; Tello et al., 2005; Raupp et al., 2006) have led to considerable and persistent argumentation for the necessity of using a more varied and stress-tolerant selection of tree species at urban sites (Richards, 1983; Duhme, Pauleit, 2000; Pauleit, 2003).

In order to acquire knowledge of a greater diversity of species adapted to urban sites, new innovative methods have to be developed. Research on e.g. the drought tolerance of trees has classically focused on physiological reactions in the water balance/water use, based on parameters such as transpiration rate, sap flow rate and the hydraulic architecture of the trees (e.g. Kozlowski et al., 1991; Sperry et al., 1998; Breda et al., 2006; David et al., 2007; West et al., 2007). These investigations provide valuable information at the tree level, but they are limited in their practical everyday use for urban tree planners, arborists, etc. (Roloff et al., 2009). As an alternative, dendroecological studies can help evaluate the reaction and tolerance of different tree species to factors such as drought, heat, pollutants, etc. According to Roloff et al. (2009), this kind of dendroecological description is seldom or never available for most species, so this type of research is needed in the selection process for "new" tree species for urban sites.

Silver lime (*Tilia tomentosa* M o e n c h), which is native to the Balkanian-Pannonian area of Europe, was introduced into Western European horticulture back in 1767 (Bean, 1980). It is described in the literature as a heat-and drought-tolerant tree species and is even ranked as the lime species which can best deal with these kinds of site conditions (Daniels, 1975; Mitchell, Jobling, 1984; Gilman, 1997; Dirr, 1998; Bassuk et al., 2009; Fini et al., 2009). In northern Europe, the experiences of silver lime are good and it has been shown to have a long-lasting health and hardiness. Against this background, it is surprising that silver lime is rare in urban environments. Instead, small-leaved lime (*Tilia cordata* L.) and common lime (*Tilia* × *vulgaris* H a y n e.) are without doubt not only the most used lime tree species at urban sites, but also the most used tree species in street environments in northern Europe (Sæbø et al., 2005). Since water stress is widely argued to be the main constraint for tree growth and health at urban sites (e.g. Whitlow, Bassuk, 1987; Craul, 1999), silver lime has to be considered a better alternative than the more moisture-demanding lime tree species. Moreover, today, silver lime is used only as an exclusive park tree in northern Europe, but in its natural range, it is widely used as a successful urban tree. For example, in the city of Iasi, Romania, silver lime is the most used street tree and indeed it is the symbol of the city. It is also the tree most frequently mentioned in the poems of the great Romanian poet Mihai Eminescu (1850–1889) (Fig. 1).

In order to develop knowledge and experience of the potential of silver lime as a suitable tree for urban sites in northern Europe, dendroecological studies were carried out in north-east Romania and in the adjacent part of the Republic of Moldavia. Investigating natural habitats experiencing similar conditions to those in the target urban environments and studying the ecological background and development of the species is considered a successful approach to finding "new" species, since both time and money can be saved (Flint,

Fig. 1. a,b. Silver lime trees in street environments in Iasi, Romania.

1985; Ware, 1994; Ducatillion, Dubois, 1997; Sæbø et al., 2005; Roloff et al., 2009). The main objectives of the present study were to: 1) identify forest types with similar climate and site conditions to urban sites in northern parts of Central Europe and in adjacent, milder parts of Northern Europe (in the following, abbreviated to the CNE-region); 2) evaluate the growth and performance of silver lime in these habitats; and 3) identify the potential of silver lime for use in urban environments in the CNE-region by comparing the field data against data for urban paved sites and park environments in Copenhagen.

Material and methods

Case study area

North-east Romania and the Republic of Moldavia have a temperate-continental climate with hot summers, long, cold winters and very distinct seasons. The field studies were carried out during September-November 2009 in three different areas (Fig. 2), all with a climate similar to that at urban sites in the CNE-region: Repedea Hill (52°82'96" N, 24°00'27" E), Codri Forest Reserve (52°95'86" N, 24°51'86" E) and Rădeşti (51°71'92" N, 24°29'35" E) (Fig. 1).

In selecting sites for the study, special attention was paid to having areas with homogeneous site conditions with mature forest trees, including silver limes. Five study plots were identified in each area, strategically placed within recognised forest stands. Plot size was 20x20 m.

Data on the climate in the field study areas were taken from the nearby meteorological stations of Iasi (Repedea Hill), Galați (Rădeşti) and Corneşti (Codri) (Sîrbu, 2003; Ursu, (2005), while data for Copenhagen were taken from DMI (2009) (Table 1).

Fig. 2. Map of Romania and eastern Moldavia. The three study areas, Codri Forest Reserve, Rădeşti and Repedea hill, are marked in red.

Measurement of plot data

In order to optimise the match between the natural habitats and the urban conditions in the CNE-region, soil texture, humus content and pH value were determined. Soil samples were collected at three different depths (0-20, 20-30, 30-50 cm) from 10 pits randomly distributed in each field plot (Klute, 1986; FAO, 2006). The replicate samples for each depth and site were pooled before analysis (FAO, 2006). Soil texture was analysed using the soil grain analyser method, organic matter using the $K_2Cr_2O_4$ method and pH using the potentiometric determination method (soil/water = 1:2) (Table 2).

In order to evaluate the growth and performance of silver limes in the study plots, trunk diameter at breast height (DBH), total tree height and tree age were determined for each individual tree. To establish age, all trees

T a b l e 1. Mean monthly temperature (°C) and precipitation (mm) in the field study areas and in Copenhagen, Denmark. Mean annual temperature (M) and cumulative precipitation (S) in the respective area are also shown.

Iasi (Repedea Hill)	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	
Mean monthly temp. (°C)	0	0.4	3.6	11.2	16.6	20.8	22	20.9	15.7	9.9	4	0	M = 10.4
Precipitation (mm)	27	28	29	36	34	64	74	70	56	48	31	35	S = 532
Galați (Rădeşti)													
Mean monthly temp. (°C)	0	0	4.1	10.6	16.5	20.3	22.6	22	17.6	11.5	5.2	0	M = 10.5
Precipitation (mm)	30.7	26.6	23.6	37.4	49.2	66.3	47.3	40.5	38.7	33.4	34.5	32.3	S = 460.5
Corneşti (Codri)													
Mean monthly temp. (°C)	0	0	1.9	9	15	18.1	20.6	20	15.5	9.6	3.1	0	M = 8.7
Precipitation (mm)	38.8	34.8	33.8	52	59.4	99.1	83.8	59.8	61.8	27.8	46	40.1	S = 637.2
Copenhagen													
Mean monthly temp. (°C)	2	2	5	10	15	19	20	20	17	12	7	4	M = 11.1
Precipitation (mm)	32	31	31	53	63	101	83	56	48	25	35	31	S = 589

T a b l e 2. Calculation of potential water stress and growth.

Area	Mean clay (%)	Mean silt (%)	Mean humus (%)	Mean pH
Codri	28.3	54.3	4.1	6.0
Rădeşti	17.3	36.2	3.7	5.4
Repedea hill	26.3	58.2	2.6	6.6

were subjected to drilling as close to the ground as possible (Grissino-Mayer, 2003). Moreover, the tree positions were surveyed to distinguish canopy from understorey.

In the urban context, it is essential to predict the growth and development of the selected tree species at the particular site. We therefore divide the evaluated growth and development of the silver lime trees in the study areas between including all trees, and the trees between age 0–50, in order to determine possible rates and trends.

Calculation of potential water stress and growth

Since water stress is the main concern for urban trees (e.g. Whitlow, Bassuk, 1987; Craul, 1999) the potential water stress in the study plots was calculated and compared with data for the inner city environment of Copenhagen, Denmark (Fig. 3). In calculating potential evapotranspiration, we used the regression by Thornthwaite (1948), with monthly potential evapotranspiration based on the values of temperature, number of sunshine hours per day and cloudiness. Sunshine hours per day were estimated on a monthly basis by combining information about day length (Meeus, 1991) and days with rainfall as an indicator for cloudiness (Ursu, 2005).

Estimates of water run-off for woodlands and urban paved areas were based on P90 (2004) and assumed 10% run-off from woodlands and park environments (study plots and Copenhagen park environments) and 70% run-off from paved areas (Copenhagen paved environments).

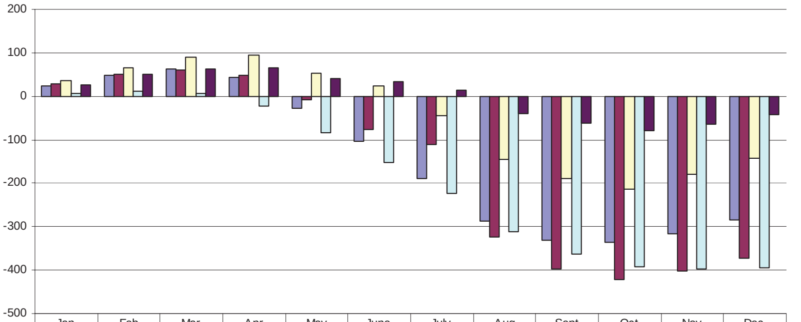
In order to evaluate the growth pattern of silver limes at the three different sites, the height and DBH were divided by age, allowing annual tree growth for the sites to be calculated.

Results

Site conditions

The soil texture was comparable at all three sites, with high levels of clay (mean 24.0%) and silt (mean 49.6%) and low organic matter content (mean 3.5%) (Table 2). In terms of climate, the Codri Forest Reserve site had lower mean temperatures and higher precipitation than the Repedea Hill and Rădeşti sites (Table 1). This climate difference is reflected in Fig. 3, which shows the potential water stress for the study areas. Codri developed a negative net water balance in July, whereas Repedea hill and Rădeşti experienced a water deficit already in May and had a much more intensive trend during the growing season compared with Codri (Fig. 3).

Comparisons of the climate at the study sites and that in Copenhagen revealed a clear difference between Codri and Copenhagen, while Repedea hill and Rădeşti had closer matches with the city, although with less precipitation and slightly lower average temperature (Table 1). Comparisons of the water stress status between the study sites and Copenhagen showed greater differences when the comparison was between natural and paved sites compared with natural and park environments (Fig. 3). There was a clear mismatch between the study sites and the park environments in Copenhagen, which only experienced a moderate water deficit, starting in August. On the other hand, the Repedea hill and Rădeşti sites and paved sites in Copenhagen showed a much closer match, although the water deficit arose at the paved sites in April and only reached a similar level as that at Repedea hill and Rădeşti in August (Fig. 3).



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Iasi (Repedea Hill	24.3	48.9	63.2	44.4	-26.9	-103.5	-189.6	-287	-331.8	-336	-317	-285.5
Galati (Rădeşti)	27.6	51.6	60	47.5	-7.4	-76.5	-109.7	-323.6	-396.5	-421.4	-401.9	-372.8
Cornesti (Codri)	34.9	66.2	89.9	93.6	52.5	24.6	-44	-145.9	-188.4	-213.3	-179.8	-143.7
Copenhagen (paved environment)	6.7	12.1	6.7	-22.1	-84.9	-152.3	-223.4	-310.6	-361.8	-392.9	-398	-395.5
Copenhagen (park environment)	25.9	49.9	63.1	66.1	41.1	34.3	13	-40.6	-63	-79.1	-63.2	-42.1

Plant development and performance – all trees

In total, there were 66 silver lime trees in the plots at Codri, 32 at Repedea hill and 64 at Rădeşti. At Codri and Repedea hill, there was a good range of age variation among the trees (9–102 years and 7–84 years, respectively). At Rădeşti, there was a lack of young individuals and the age range was 24–84 years. However, the numbers of lime trees in the plots and the age range of these trees were considered sufficiently high to plot height and DBH as a function of tree age (Figs 4 and 5, respectively).

The silver lime trees at Repedea hill had an annual height increment of 41 cm, compared with 32 cm at Codri and 38 cm at Rădeşti (Table 3). In terms of diameter, the annual increase was highest for trees at Repedea hill (0.63 cm), where it was almost twice that at Codri (0.32 cm) (Table 3). Overall tree height as a function of age was similar at Repedea hill and Codri, but on average the trees were 3 m higher in the Repedea hill area (Fig. 4).

Table 3. Mean increment in height (m) and DBH (cm) for silver limes in plots at the study sites.

Study area	**Height increment (m)**	**DBH (cm)**	**Number of trees**
Codri	0.32	0.37	66
Rădeşti	0.38	0.48	64
Repedea Hill	0.41	0.63	32

The Rădeşti forest had a much slower growth pattern, as indicated by a flatter slope on the growth line, mainly due to the lack of young individuals. However, this lack of young individuals at Rădeşti was not reflected in annual height increment, since Rădeşti has a stronger annual growth than Codri (38 cm compared with 32 cm) (Table 3).

In terms of DBH, the growth pattern shown in Figure 5 illustrate the same misleading guidance, with a shown slow growth at Rădeşti, even though the calculated DBH growth shown in Table 3 illustrated a stronger annual growth for Rădeşti forest than for Codri due to the lack of young individuals. The diameter growth for Repedea hill follow the height growth pattern, while the trees in Codri had a stronger height growth than diameter growth over time (Figs 4 and 5).

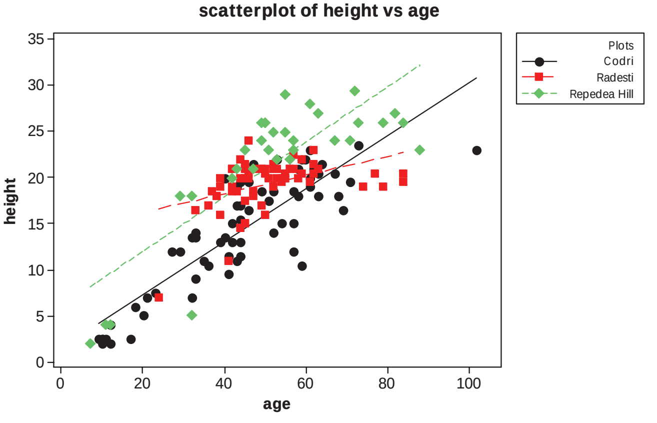


Fig. 4. Height increment (cm) of all silver lime trees in the three study areas as a function of tree age (years).

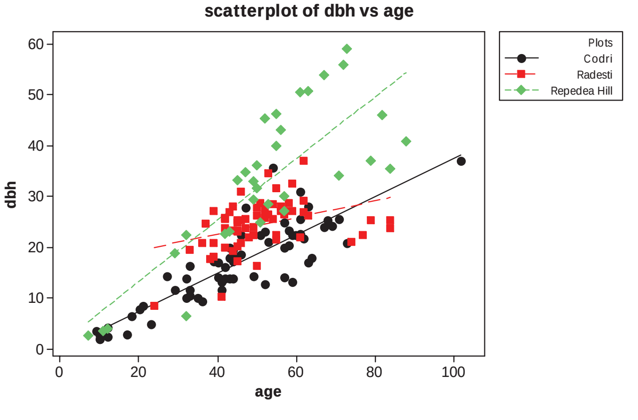


Fig. 5. DBH increment (cm) of all silver lime trees in the three study areas as a function of tree age (years).

Concerning the vertical distribution of the silver limes in the plots, the majority of trees on Rădeşti and Repedea hill were situated in the canopy layer, exposed to higher temperatures with a much more effective transpiration (Fig. 6). Among the trees in Codri, there were a much higher amount of trees in the understorey layer, where the site conditions are cooler and somewhat less dry (Fig. 6).

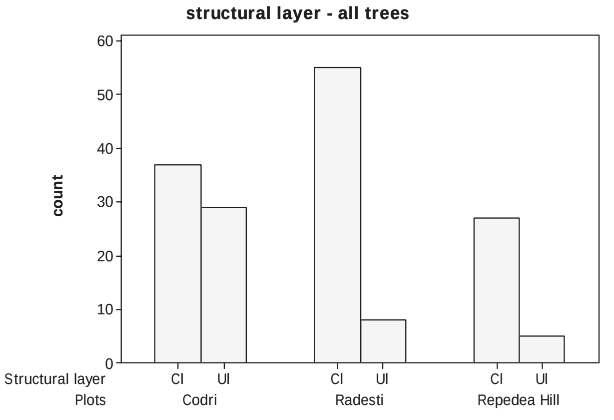


Fig. 6. Vertical distribution of silver lime trees found in the study plots including all trees divided into understorey layer (Ul) and canopy layer (Cl).

Plant development and performance – 0–50 year-old trees

There was a similar distribution of trees less than 50 years of age in all areas. Thus, 43% of all silver lime trees present were less than 50 years old at Repedea hill, 54% at Rădeşti and 60% at Codri. The annual height increment of these < 50-year-old trees was 48 cm at Repedea hill, 43 cm at Rădeşti and 35 cm at Codri. In terms of trunk diameter growth (DBH), the annual increment was 0.60 cm at Repedea hill, 0.51 cm at Rădeşti and 0.37 cm at Codri (Table 4).

The largest difference in growth pattern between all silver limes in the plots (Table 3) and trees under the age of 50 (Table 4) was observed for Rădeşti. A more accurate pattern of the development and growth of the silver limes at Rădeşti was probably obtained when the

T a b l e 4. Mean increment in height (m) and DBH (cm) for silver lime trees aged between 0 and 50 years at the study sites.

Plot area	**Height increment (m)**	**DBH increment (cm)**	**Number of trees**
Codri	0.35	0.37	40
Rădeşti	0.43	0.51	35
Repedea Hill	0.48	0.60	14

older trees (> 50 years) were excluded, due to their declining growth and the low number of young trees. For Codri and Repedea hill, the height growth patterns are similar as when including all trees (Figs 2 and 3), yet with a stronger growth in height (Table 4). Due to diameter growth, the trees on Repedea hill showed a similar growth pattern as to height growth, while the trees in Codri showed a slower diameter growth compared with height growth over time (Figs 7 and 8).

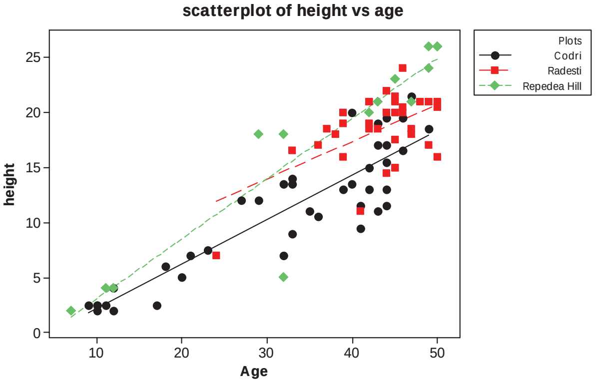


Fig. 7. Height increment (cm) of silver lime trees aged between 0 and 50 years in the three study areas as a function of tree age (years).

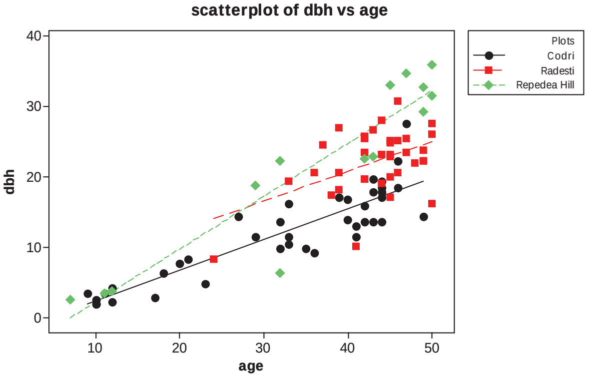


Fig. 8. DBH increment (cm) of silver lime trees aged between 0 and 50 years in the three study areas as a function of tree age (years).

Concerning the vertical distribution of the silver limes under 50 years of age, the majority of the trees in Codri were situated in the cooler and moister understorey layer while the majority of the trees in Rădeşti were in the warmer canopy layer (Fig. 9). On Repedea hill, the position of the silver limes under 50 years of age were slightly evenly divided between understorey- and canopy layers (Fig. 9).

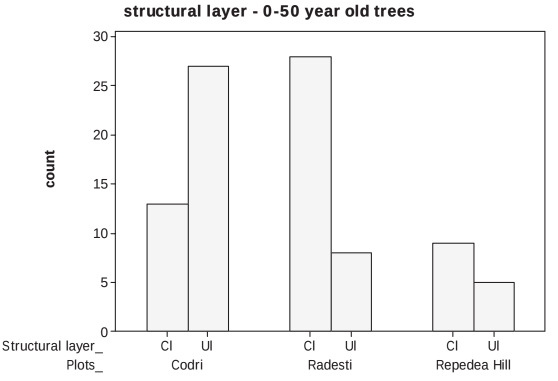


Fig. 9. Vertical distribution of silver lime trees found in the study plots including trees under age of 50 divided into understorey layer (Ul) and canopy layer (Cl).

Discussion

Site conditions

The evaluation of site conditions revealed clear similarities in the three different study areas concerning soil texture, with high levels of clay and silt in all plots (Table 2). Although the soil humus content at the sites was low (Codri 4.1%, Rădeşti 3.7% and Repedea hill 2.6%), the water-holding capacity can be considered very good (Craul, 1999) (Table 2). These favourable growth conditions counteracted the cumulative water deficit calculated for the study sites (Fig. 3). For example, although there was a 26.9 mm deficit at Repedea hill in May, water was probably accessible to the trees for much longer periods due to the good water-holding

T a b l e 5. Effect of reducing run-off rate to 50%, 40% or 30% on cumulative net water balance in Copenhagen.

Cumulative water balance (mm) at Copenhagen with:	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
50% run-off	13.1	24.7	25.5	7.3	-42.9	-90.1	-144.6	-220.6	-262.2	-288.3	-286.4	-277.7
40% run-off	16.3	31.0	34.9	22.0	-21.9	-59.0	-105.2	-175.6	-212.4	-236.0	-230.6	-218.8
30% run-off	19.5	37.3	44.3	36.7	-0.9	-27.9	-65.8	-130.6	-162.6	-183.7	-174.8	-159.9

capacity of the soil. Moreover, since silt has very good capillary water transporting capacity, groundwater can be transported upwards from depth and become accessible for the trees. Therefore, the apparent close match in cumulative water deficit between Rădeşti/Repedea hill and paved sites in Copenhagen is actually inaccurate in terms of the drought stress experienced by the trees. However, it is possible to state that the silver limes at Rădeşti and Repedea hill, which experience warmer and drier conditions than Codri, also experience much warmer and dryer growing conditions than park environments in Copenhagen (Fig. 3). In an attempt to evaluate the match between urban paved sites in Copenhagen and the natural study sites, calculations were made for different rates of water run-off at the urban paved sites (Fig. 5). The results showed a much smaller net water deficit when run-off was reduced, from 70% in the original calculations to 50, 40 or 30%. This clearly shows the importance of proper planning and design for providing suitable site conditions and the prevention of run-off.

Plant development and performance

In total, 162 silver lime trees were included in the study (66 at Codri, 64 at Rădeşti and 32 at Repedea hill), and these limited numbers cast some doubt on the results of the study. The low numbers were because silver limes in north-east Romania and the Republic of Moldova grow in mixed broad-leaved forests mainly dominated by various oak species (e.g. *Quercus dalechampii* T e n., *Q. pedunculiflora* K. K o c h) and hornbeam trees (*Carpinus betulus* L.), with only scattered individuals of silver lime. However, the sites were selected as having a comparatively high proportion (32%) of silver lime trees among the total of 508 trees, divided among 12 species in the study. Yet, some qualitative conclusions can thus be drawn on the potential of silver limes originating from the study region for use at urban sites in the CNE-region.

The growth pattern of the trees at Codri was interesting. Despite higher mean annual precipitation and lower summer temperatures, which resulted in lower evapotranspiration, the Codri trees grow more slowly than those in the warmer, drier climate at Rădeşti and Repedea hill. Since the available water content was not that critical, even on drier sites such as Rădeşti (Fig. 3), higher temperatures clearly influence the height and diameter growth of silver lime, which were higher at Rădeşti and Repedea hill than at Codri (Tables 4 and 5). This makes the silver lime valuable for warmer inner city environments, where many tree species native to the CNE-region suffer due to higher summer temperatures.

In order to further evaluate the stress tolerance of silver lime trees, it is important to identify their vertical distribution which have to be included in the total analyse of the development and performance data. Trees in the canopy layer positively modify the wind, humidity, and temperature microclimate for the species in the understorey layer, while the canopy species suffer from a much more effective transpiration due to their exposure to warmer temperatures (Oliver, Larson, 1996). In the study plots, silver lime exist in understorey layer as well as in canopy layer in all the study areas, indicating tolerance for the warm and dry climate of the region as well as for shady conditions (Figs 6 and 9). The latter is important in the use of silver lime in urban environments, where the urban structure with buildings create really shady local conditions.

Moreover, due to earlier and unrecorded variation in the species compositions in the stands, additionally with earlier competitive situations, the analyses of the growth data presented in the paper should be interpreted with some consideration. However, the growth and development data can still act as a guideline in species development in these climate and site situations. To get even more accurate data, it is important to test the silver lime origin from this area in urban plantations in the CNE-region. From these plantations, local experiences can be gained, but dendroecological studies in climates and in natural site situations similar to urban environments of the CNE-region can be used as a first selection step in order to concentrate on species with high potential, instead of randomly testing a selection of trees, since this is a time-consuming process.

Conclusion

This study examined the potential of silver lime (*Tilia tomentosa* M o e n c h) for use as an urban tree in northern parts of Central Europe and adjacent, milder parts of Northern Europe (the CNE-region), based on habitat studies in north-east Romania and in the adjacent Republic of Moldavia. The data obtained in the field were compared with corresponding data from paved and park environments in urban Copenhagen. In this comparison, the result shows that the study trees experience warmer and drier site conditions than park environments in Copenhagen, while the paved environment in Copenhagen experience drier site conditions than the case in the studied sites. However, if a proper design and technique is used in paved sites with a greater infiltration into the planting pits, the site situations become much more similar to the studied sites, indicating that the silver limes also have use potential in paved environments in the CNE-region, where they can develop into old and healthy trees.

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