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Effect of street conditions, including saline aerosol, on growth of the Small-leaved limes

Wpływ warunków przyulicznych, w tym aerozolu solnego, na wzrost lip drobnolistnych

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Abstract: There is increasing number of trees dying in large urban agglomerations. The problem is mostly pronounced in the case of street trees. In Polish cities, apart of pollutions generated by traffic, an important factor that causes death of trees is high salt concentration as a result of winter salt application for de-icing of streets. The aim of the study was to assess the growth of limes (*Tilia cordata*) planted along highly trafficked Warsaw street and exposed, among others, to salt in a form of saline aerosol. The assessment of shoot length, tree height and crown volume, based on the photographic method of the three increment assessments, showed very restrained growth of the studied limes. In the years 2006-2008 the trees performed so poorly as in similar period of 2003-2005 and grew worse than limes form natural habitats. In 2009 we even observed decrease in size of street trees as compared to 2008 which suggests both very bad condition of street habitats and the studied trees. Salt concentration measured on the surface of tree buds and shoots (EC) was higher in street trees than in trees from natural habitats, which indicates that saline aerosol is the source of sodium chloride. We observed highly diversified reactions of individual trees to the whole complex of street conditions. It is therefore recommended to select for propagation individuals from among most tolerant and vigorously growing plants (genotypes) to be used in street planting.

Key words: street trees, salinity stress, de-icing salt, urban trees, *Tilia cordata*

Introduction

There is increasing number of dying trees observed in large city agglomerations. The problem refers not only to young plants but also to older, larger trees. In Warsaw during the last 25 years only, the number of trees decreased by half (Breś 2008). The most severely damaged are those planted along the streets. This situation is found also in other cities, not only Polish, as the problem is global (Nowak et al. 2004). In order to overcome this effect it is necessary to reveal the causes of trees' death and understand the mechanisms of this phenomenon.

It is specificity of the Polish cities to use large quantities of salt to de-ice streets during winter, which seems the only way to cope with the frost glaze. Initially, in winter of 1969/1970, when this chemical method was applied for the first time, up to 22 000 tones of mixture composed in 95% of NaCl and 5% of $CaCl_2$ was used. As early as in 1970 substantial loss in street trees was observed (Czerwiński 1970). After that an instruction was issued that restricted the methodology and quantity of chemical substances used. It was stated that a single application of chemical substances should not exceed 30 g/m^2 and the total seasonal acceptable dose should not exceed 2 kg/m^2 of a street (Czerwiński 1978).

Street salt has been continuously used until now, although it disturbs soil chemical composition and is an evident cause of trees' death in urban agglomerations. It causes the loss of up to 90% of trees growing along heavily trafficked streets (Breś 2008). Sodium chloride used since 1968 for street de-icing results in increase of Na^+ and Cl^- ions content but also in very harmful sodium carbonate and bicarbonate in upper soil layers, which indirectly induce increase of soil pH (Wrochnia et al. 2006). The salt however affects plants not only via root system, but due to traffic, its application in streets, it diffuses as an aerosol and adheres to tree's shoots and buds. This kind of negative effect was discussed, among others, by Pracz (1990), Cunningham et al. (2007) and Borowski (2008).

The trees' condition is most easily assessed based on description of their above-ground parts. In many species is its best done during their leafless period. Assessment of the tree's condition in full leaf is difficult due to foliage dependence on many factors that may act adversely and for a very short time (Roloff 2001). For this reason in the present study we assessed the trees' condition in the leafless state.

Aim

The aim of the study was to assess the growth of lime trees planted along the heavy trafficked street, and exposed, among others, to saline aerosol. The work aimed also at showing the differences of growth reaction of individual trees exposed to the complex of street conditions.

Methods

Choice of study trees

For the study we chose Small-leaved limes (*Tilia cordata*) planted along Sikorski Alley in Warsaw. Sikorski Alley is a six-lane wide artery that belongs to the most heavy trafficked streets in the city used in the afternoon rush hours by 3116 vehicles/h in direction Dolina Służewiecka-Sobieskiego Street and 3487 vehicles/h in direction Sobieskiego Street-Dolina Służewiecka (data according to Bureau of Warsaw Development Planning /Biuro Planowania Rozwoju Warszawy S.A.). Both sides of the alley, from Wilanowska Alley onwards, to the crossing with Sobieski Street, are planted with coeval limes. The distance between the street and the tree line was approx. 3 m and between the tree line and sidewalk approx. 1.5 m.

Study methods – photographic method of tree increment assessment

To compare the growth of the chosen trees we used the photographic method of tree increment assessment (Borowski, Pstrągowska 2005, Borowski 2008). The method is based on repeatable photography. Photographs of leafless trees were take always from the same point between subsequent vegetation periods. To compare tree growth we used measurements of shoots increments, tree height and crown volume. The measurements in the last years were taken in February 2009 and February and November 2010. For comparisons of the tree growth in longer period we used measurements done by Borowski (2008) taken in the years 2003-2006. This enabled us to compare three-year long vegetation periods from the years 2003-2005 and 2006-2008. Measurements taken in 2009 and 2010 allowed for comparisons of the earlier data.

In the years 2003-2006 relatively high number of trees were measured (22), while only 13 were studied in subsequent seasons. This discrepancy was due to decrease in tree number (some of individuals were removed) and changing photographic conditions that made some of the initially chosen trees impossible to photograph.

Study methods – salt concentration measurements in tree shoots and buds

In March 2009 we collected the youngest, one-year old shoots and buds of the Small-leaved lime growing in Sikorski Alley. Shoots and buds were collected from the height of 1.5-2 m from two opposite sides of the tree, one facing the street (category I) and the other facing the sidewalk (category II). To compare the results we collected also coeval shoots and buds of Small-leaved lime growing in natural conditions of the Kabacki Forest (category III).

Salt concentration on the shoot surface was assessed by dissolving salt in distilled water and measuring of EC conductance of the resulting solution. Cut shoots were placed tip-down one by one in a glass vial containing 120 ml distilled water until water level reached 140 ml, which allowed to measure the same volume (20 ml) of shoots in each category. Assuming similar diameter of coeval shoots of Small-leaved lime, identical solvent volume allowed to dissolve salt from the similar surface area. The content of each vial was mixed for 60 s. EC measurements were done after 60 min for three samples from each category.

Salt concentration on buds was assessed by measuring conductance of the solution resulting from dissolving salt from 6 g of tree buds collected for each of the categories. We put the buds into a vial containing 40 ml distilled water and mixed it for 60 s. EC measurements were done after 60 min for three samples from each category.

Statistical analyses (t-Student test for unpaired samples and one-way ANOVA) were conducted using STATISTICA package. We also calculated linear trends for increments of shoot length, tree height and crown volume.

Results

To calculat1e increments using the photographic method we made photographs in the years 2002-2006 and 2009-2010. For these years we could assess the shoot length, tree height and crown volume. There were no statistically significant differences in trees increments during the two three-year long periods of 2003-2005 and 2006-2008. During both periods the values were low. In the years 2003-2005 the length of all shoots assessed using the photographic method increased by 17.66%, tree height increased only by 5.54% and crown volume by 13.59% (Fig. 1). In the second three-year long period of 2006-2008 tree shoots increased in length by 22.29%, crown volume increased by 22.25% and tree height decreased by 8.63%. In the years 2006-2008 we observed increased diversity in the growth tempo of individual trees (Fig. 1, Table 1).

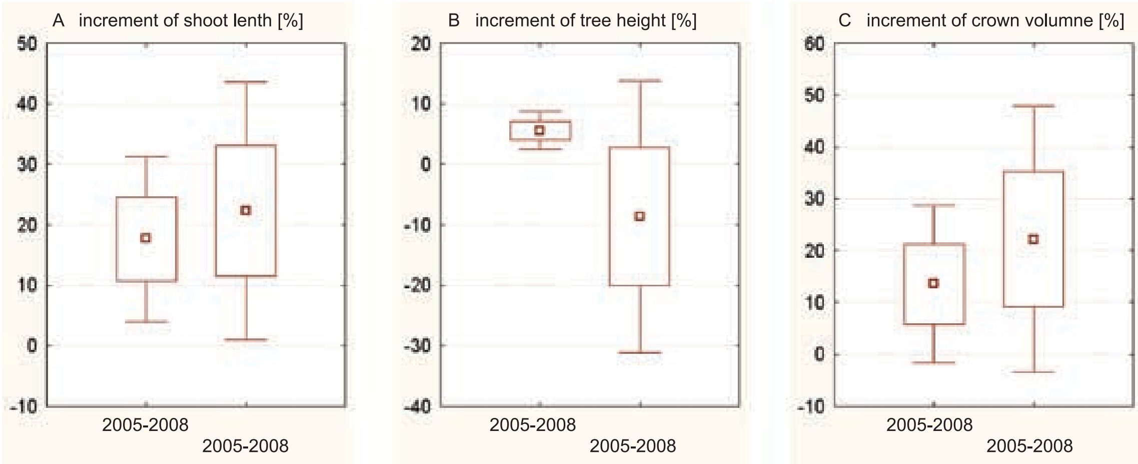


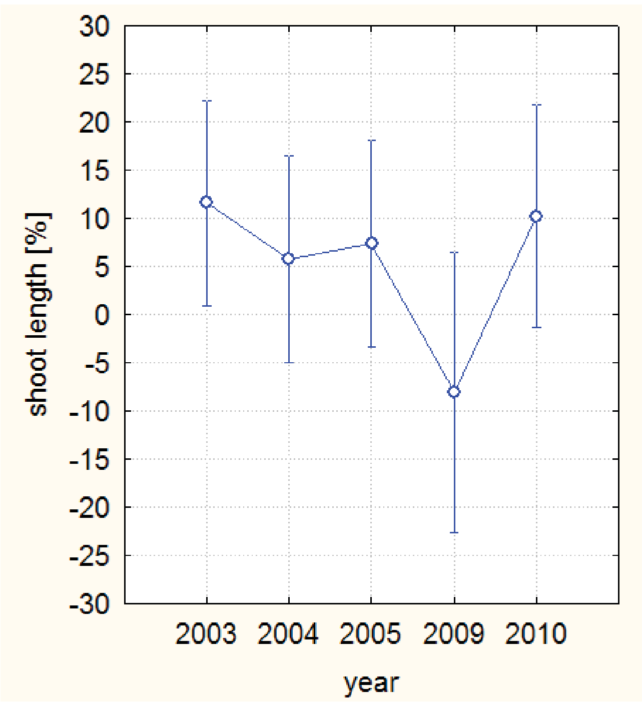
Fig. 1. Three-year long increments (%) of crowns of street limes in the years 2003-2005 and 2006-2008.
A – increment of shoot length, B – increment of tree height, C – increment of crown volume; t-Student test for unpaired samples

Table 1. Comparison of three-year long increments,
A – shoot length, B – tree height, C – crown volume in the years 2003-2005 and 2006-2008

		mean		t	df	p	N		St. Dev.	
		I	II				I	II	I	II
A	I shoot length 2003-2005 vs. II shoot length 2006-2008	17,66	22,29	-0,377	20	0,7102	13	9	25,0823	32,5072
B	I tree height 2003-2005 vs. II tree height 2006-2008	5,54	-8,63	1,473	20	0,1564	13	9	5,7382	34,3627
C	I crown volume 2003-2005 vs. II crown volume 2006-2008	13,59	22,25	-0,606	20	0,5513	13	9	27,9003	39,3453

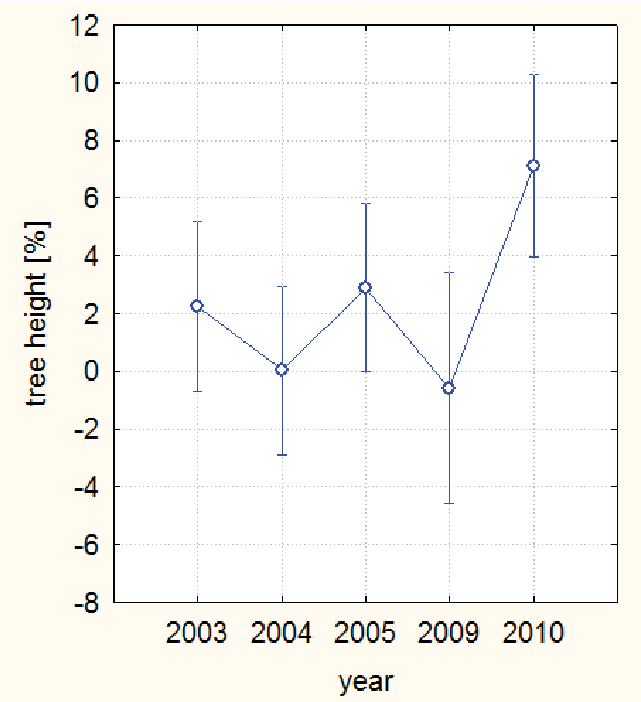
We found significant differences in annual tree increments. The smallest increment was observed in 2009 and all measurements done in that year (shoot length, height and crown volume) showed negative numbers (Figs. 2, 3, 4).

Of course, the growth of individual trees was more diversified than mean value for all studied individuals.



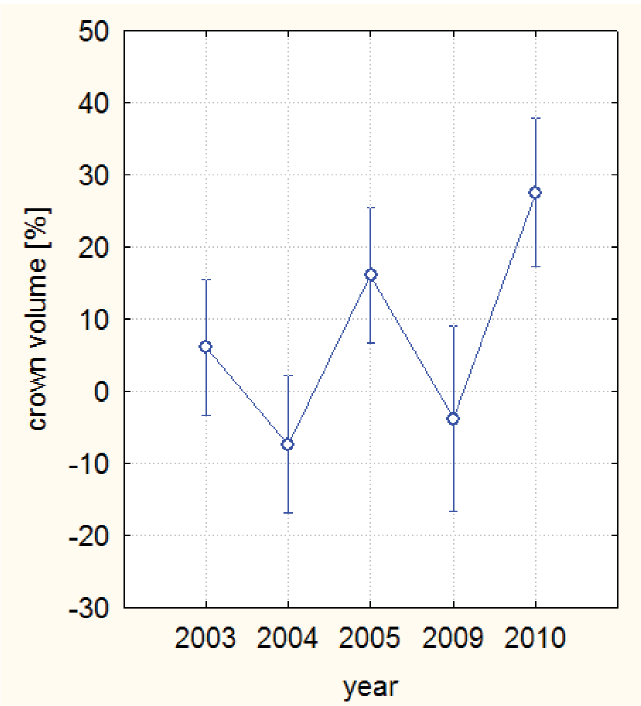
year	shoot length [%]	1	2
2009	-8,05		****
2004	5,74	****	****
2005	7,36	****	****
2010	10,23	****	
2003	11,58	****	

Fig. 2. Annual increments (%) of shoot length of Small-leaved lime in Sikorski Alley. Error bars represent 0.95 confidence interval, $F(4, 52) = 1.3483$, $p = .26464$; 1, 2 – homogenous groups



year	tree height [%]	1	2
2009	-0,58	****	
2004	0,02	****	
2003	2,25	****	
2005	2,90	****	****
2010	7,13		****

Fig. 3. Annual increments (%) of tree height of Small-leaved lime in Sikorski Alley. Error bars represent 0.95 confidence interval, F(4, 52) = 3.4736, p = .01373; 1, 2 – homogenous groups



year	crown volume [%]	1	2	3
2004	-7,36	****		
2009	-3,79	****		
2003	6,15	****	****	
2005	16,06		****	****
2010	27,52			****

Fig. 4. Annual increments (%) of crown volume of Small-leaved lime in Sikorski Alley. Error bars represent 0.95 confidence interval, F(4, 52) = 7.9157, p = .00005; 1, 2, 3 – homogenous groups

(Figs. 5, 6, 7). Based on measurements of shoot length, height and crown volume, we divided the studied trees into two categories (Figs. 8, 9, 10). The precise division was possible thanks to the analysis of the linear trends (Table 2). The first category, growing trees, included individuals for which at least two of the assessed parameters showed increase (e.g. limes 37, 39, 40; Fig. 8). The second category, dying trees, included trees for which two of the assessed parameters showed decrease or were invariant (e.g. limes 36 and 42; Figs. 9 and 10, Table 2). Based on the above assumptions six of the studied trees were assessed to growing trees category and seven to the other.

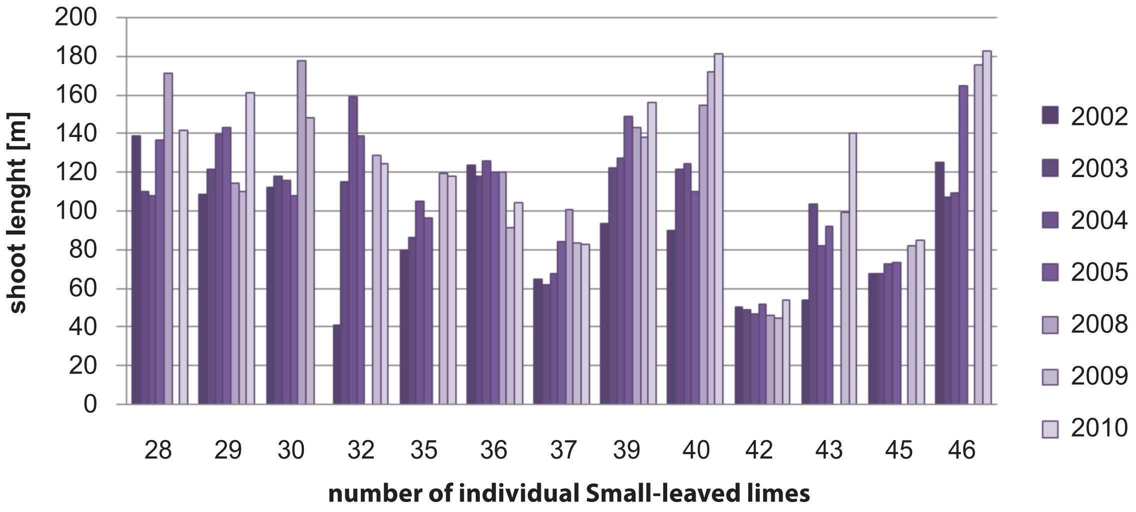


Fig. 5. Shoot length of 13 studied Small-leaved limes grown in Sikorski Alley assessed using the photographic method at the end of each vegetation period

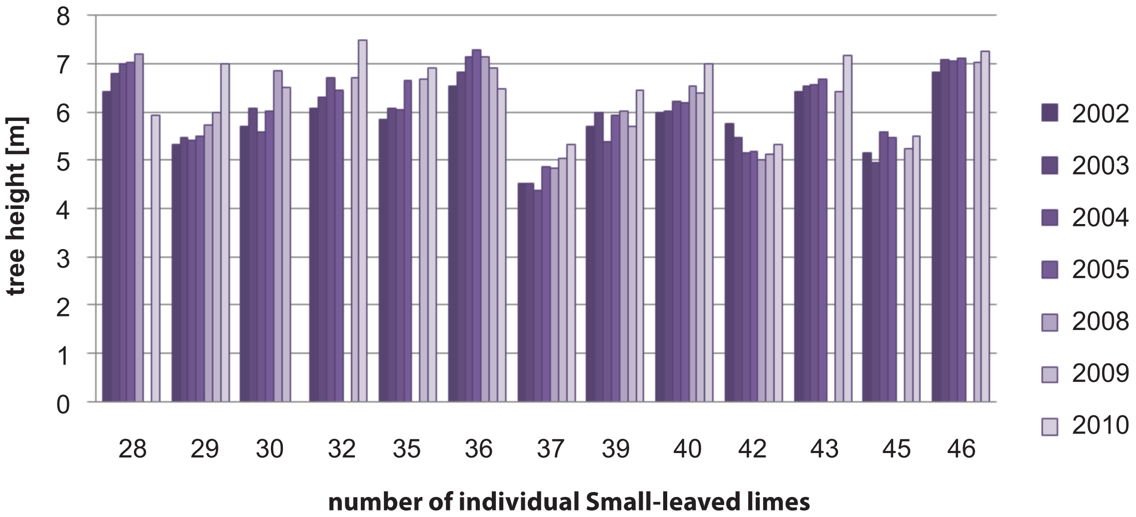


Fig. 6. Height of 13 studied Small-leaved limes grown in Sikorski Alley assessed using the photographic method at the end of each vegetation period

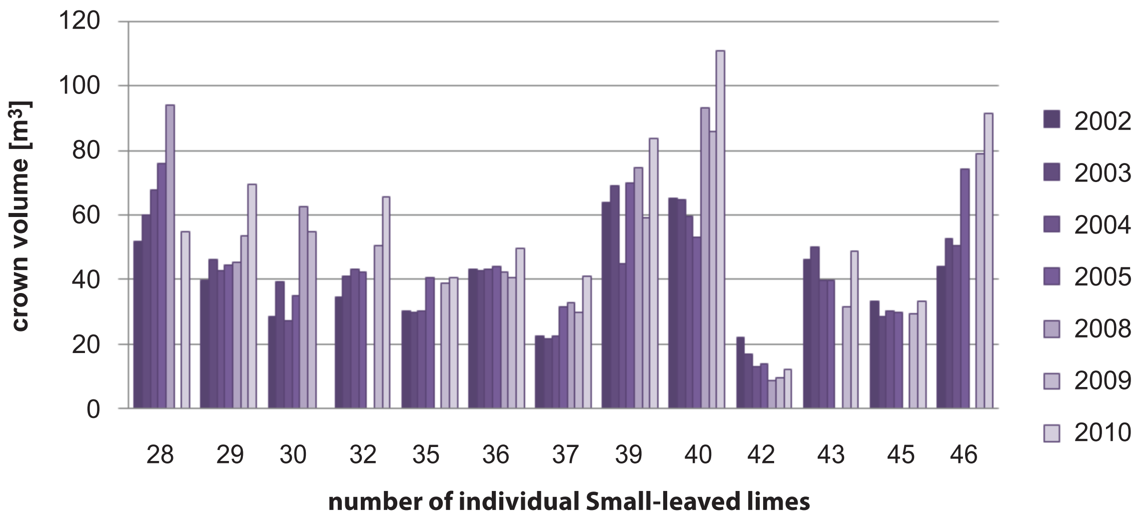


Fig. 7. Crown volume of 13 studied Small-leaved limes grown in Sikorski Alley assessed using the photographic method at the end of each vegetation period

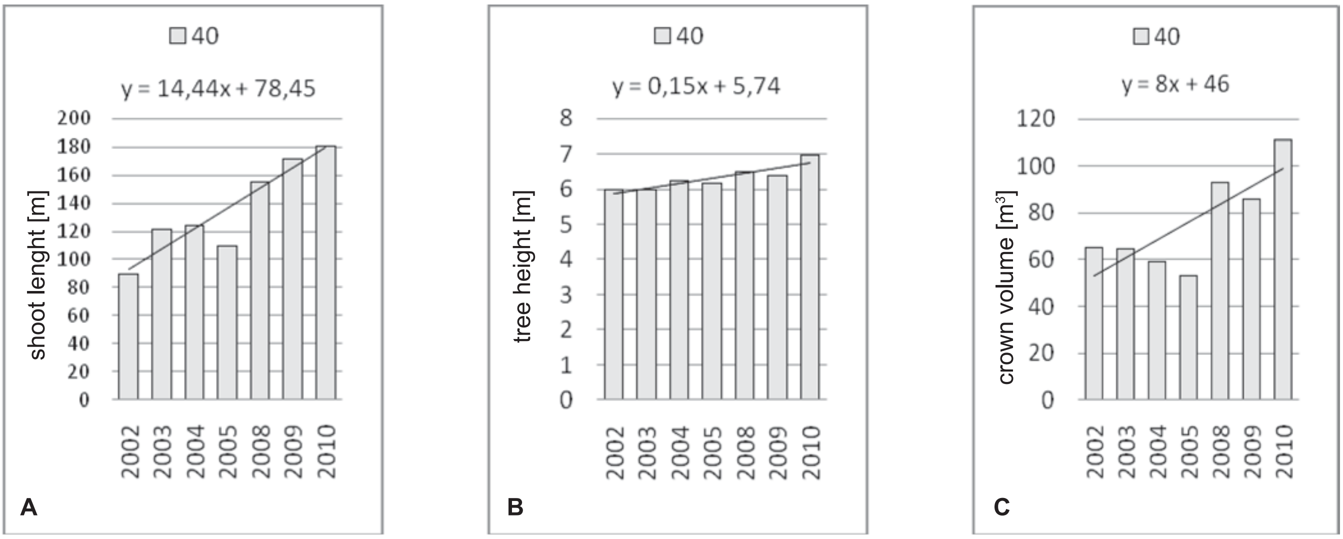


Fig. 8. An example tree for which all the studied parameters show increase (lime no. 40).
Shoot length – A, height – B, crown volume – C, and linear trends

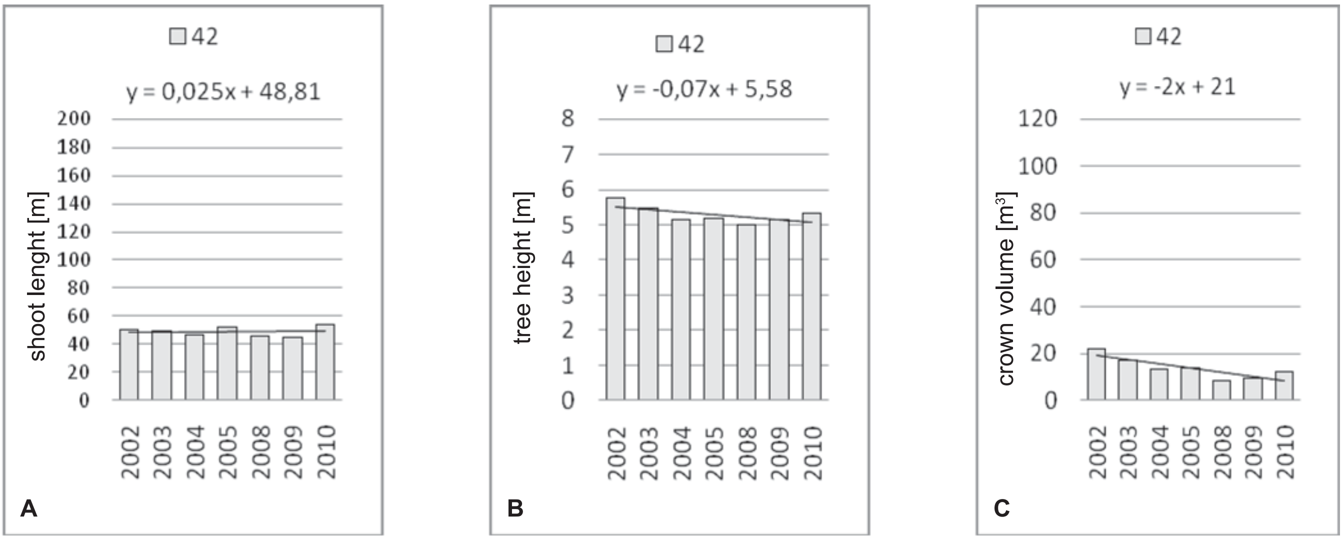


Fig. 9. An example tree for which two of the studied parameters show decrease (lime no. 42).
Shoot length – A, height – B, crown volume – C, and linear trends

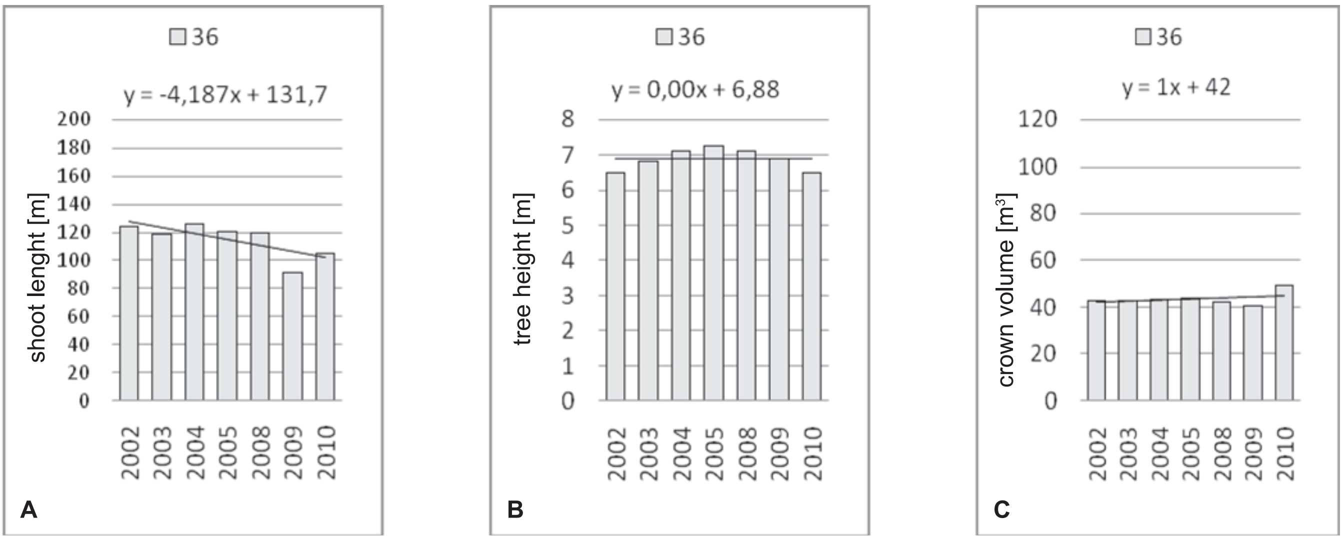


Fig. 10. An example tree for which all the parameters are relatively constant (lime no. 36).
Shoot length – A, height – B, crown volume – C, and linear trends

Table 2. Linear trends y=ax+b calculated on the basis of changing shoot length, tree height and crown volume in the study years 2003-2010 and division into growth categories

no. of lime	shoot length	tree height	crown volume
28**	y = 5x+115	y = -0,09x+6,93	y = 2x+60
29*	y = 4x+112	y = 0,23x+4,85	y = 4x+33
30*	y = 10x+95	y = 0,20+5,43	y = 6x+20
32*	y = 9x+84	y = 0,19x+5,90	y = 4x+30
35**	y = 7x+75	y = 0,18x+5,67	y = 2x+27
36**	y = -4x+131	y = 0x+6,88	y = 1x+42
37**	y = 4x+60	y = 0,08x+5,55	y = 3x+17
39**	y = 8x+99	y = -1x+45	y = 2x+56
40*	y = 14x+78	y = 0,15x+5,74	y = 8x+46
42***	y = 0,025x+49	y = 0,17x+5,58	y = 2x+21
43**	y = 10x+58	y = 0,08x+6,33	y = -1x+47
45*	y = 3x+63	y = 0,05x+5,12	y = 0x+31
46*	y = 13x+95	y = 0,04x+6,88	y = 8x+35

* growing trees – parameters increase
** dying trees – parameters are relatively constant
*** dying trees – at least two parameters decrease

Salt concentration on bud and shoot surface was dependent on the collection site (Tables 3, 4). In both cases we observed statistically significant differences among the plant material from street trees and the Kabacki Forest, and between the street facing side and sidewalk side of the trees.

Table 3. Salt concentration on shoot surface of the Small-leaved limes from Sikorski Alley and Kabacki Forest. Duncan test, 1, 2, 3 – homogenous groups, α = .05000, error: MS among-group = 128.15, df = 24,000

	Category	Shoots EC [μScm^{-1}]	1	2	3
I	forest tree	20,9222	****		
II	street tree (sidewalk side)	233,2222		****	
III	street tree (street side)	244,3333			****

Table 4. Salt concentration on bud surface of the Small-leaved limes from Sikorski Alley and Kabacki Forest. Duncan test, 1, 2, 3 – homogenous groups, α = .05000, error: MS among-group = 2317.3, df = 24,000

	Category	Buds EC[μScm^{-1}]	1	2	3
I	forest tree	51,089	****		
II	street tree (sidewalk side)	269,33		****	
II	street tree (street side)	322,88			****

Discussion

In both three-year long study periods trees' increments showed similar tempo which suggests relatively stable habitat conditions present in vicinity of our study arterial road in Warsaw. Although Small-leaved limes along Sikorski Alley grew slightly better in the second than in the first three-year long study period, when compared to increments of trees growing in relatively natural conditions in the years 2003-2005 they exhibit much inferior performance. Increments of the trees in Kabacki Forest in the years 2003-2005 showed considerable increase in shoot length (47.5%), tree height (26.1%) and crown volume (123.1%) (Borowski 2008). Street trees in the years 2006-2008 grew worse and shoot length increased only by 22.3%, tree height by -8.6% and crown volume by 22.3%.

Constant decrease in number of study trees also indicates bad growing conditions of the street side in Sikorski Alley in Warsaw, during the study period almost 25% of trees were removed. Lower number of trees measured recently caused the mean increments to be larger than those given by Borowski for the years 2003-2005. It is poor performance of many, now not existing trees, that caused the mean of the shoot length increments (7.4%) and crown volume (12.9%) to be lower during that period.

Decrease in tree height observed in the recent years suggests that some peripheral shoots die out or fall of the tree, an effect known as "horned crowns" (Clark, Matheny 1991). Crowns of many street trees are fragmented, fall apart and lose their characteristic dense lime shape. Such symptoms were called by Roloff (2001) a state of resignation. He described natural processes of tree development, senescence and death. The state of resignation as such is typical for old trees, while the limes in Sikorski Alley are relatively young (20-25 year old). It is likely that in this case we face the beginning of death of the remaining trees in this street.

Our result indicates lack of tolerance of Small-leaved lime for the street conditions underlined by many authors (Łukasiewicz, Łukasiewicz 2006, Seneta, Dolatowski 2008, Borowski 2008).

Different results obtained for subsequent years are caused by two main factors: genetic properties (genotype) of individual trees and weather conditions and other environmental factors acting on trees. The former seem mostly connected to the dominant role of salt concentration. This factor, regarded as the key one, is indicated by foreign (Ruge 1978, Cunningham et al. 2007) and Polish authors (Pracz 1990, Borowski, Latocha 2006, Bach et al. 2007). Shoot death caused by high salt concentration is for example confirmed by studies from Krakow and Częstochowa (The Blessed Virgin MaryAlley). The authors observed the death of approx. 10% of the youngest peripheral and apical shoots. It has been noticed that trees growing by the street crossings are more degraded than those planted in the alley axis (Bach et al. 2007).

According to Roloff (2001) limes drop off dead branches during one-two or even ten years. It is possible that the process of dying and falling off of dead shoots extended in time makes the identification of causes of the phenomenon observed in Sikorski Alley difficult. This is why the correlation of the growth processes of trees with weather condition and salt concentration is uneasy.

Possibly a very low mean increase of tree height measured in 2009 was caused by dropping of shoots after very snowy winters of 2004/2005 and 2005/2006 and not by low increments in that year. The character of the photographic method used allows for assessment and comparison of shoot length in various years – which is an advantage. However it does not help to tell apart whether low tree increments are caused by dropping of shoots that died in previous years or by poor performance of the tree in the year of a measurement. The method does not allow to distinguish dead from living shoots. This may explain why very snowy winter of 2009/2010 and large quantity of salt used for de-icing did not caused decrease in tree increments in 2010.

Many trees in Sikorski Alley grow poorly, their shoots die back. Dying of shoots and fragments of the tree crown are definitely more pronounced from the side of the street than from the sidewalk which indicates other than root-based causes of the phenomenon. Deformations of this kind of are caused by a growth restraining toxic factor which is not systemically distributed via water-transporting system of the plant (toxic substances which are transported via roots from soil water usually cause uniform dying of all the crown parts). Asymmetric crown deformations indicate the presence of a factor which gradient changes fast and significantly proportionally to the distance from the source, which are street and associated pollutions in this case. Salt aerosol is a likely candidate. Water solution prepared from rinsed shoots and buds of street trees had respectively over ten-fold and six-fold higher electric conductance when compared to trees from Kabacki Forest, which indicates salt aerosol precipitation on the plant organs. Statistically significant difference in EC for plant material taken from various parts of the crown (street facing vs. sidewalk facing) indicates rather restrained distribution of the salt aerosol. This suggestion is confirmed by measurements done on limes growing in another Warsaw street, Żwirko and Wigura Alley (Borowski, Stępień 2010). The study showed that salt concentration (EC) on shoots and buds collected from trees planted closest to the street edge (3 m) was much higher (ten-fold and twelve-fold respectively) than those from trees growing 10 and 30 m from the street.

Many growth deformations were observed in limes planted in Sikorski Alley. They include appearance of witch's broom-like shoots especially from the street facing side of the tree and dying back of many shoots in the crowns (Figs. 11, 12, 13).

Fig. 11, 12. Street limes from Sikorski Alley in Warsaw.
Visible are asymmetric crowns with witch's broom-like shoots from the street facing side of the tree and irregular spring growth (phot. J. Borowski, 2008-2009)

Fig. 13. Witch's broom-like structure of shoots from the street facing side of the tree
(phot. J. Borowski, 2009)

Asymmetric crown deformations and witch's broom-like structure of shoots as a reaction for dying of buds caused by salt aerosol was stressed, among all, by Dirr (1976), Trowbridge and Bassuk (2004).

Salt aerosol is a previously underestimated factor, its effect increases together with increased traffic and speed of vehicles. In Polish urban conditions there is also increased public demand for proper winter maintenance of streets, which includes salting truck actions, especially that this coincides with snowy winters, such as those in the year 2004/2005, when in Sikorski Alley there were 50 events of salt application, or 2005/2006 – 47 salt applications or 2009/2010 – 53 salt applications (data from Zakład Oczyszczania Miasta / City Maintenance Bureau of Warsaw 2010).

Observation of trends of increase in particular lime parameters allowed to notice individual differences in growth tempo of approx. coeval trees from the same species growing in nearly identical habitat conditions. Some of the studied trees remained of constant size (e.g. lime no. 42), increments of other trees were smaller in the subsequent year when compared to the year of the study (e.g. limes no. 29

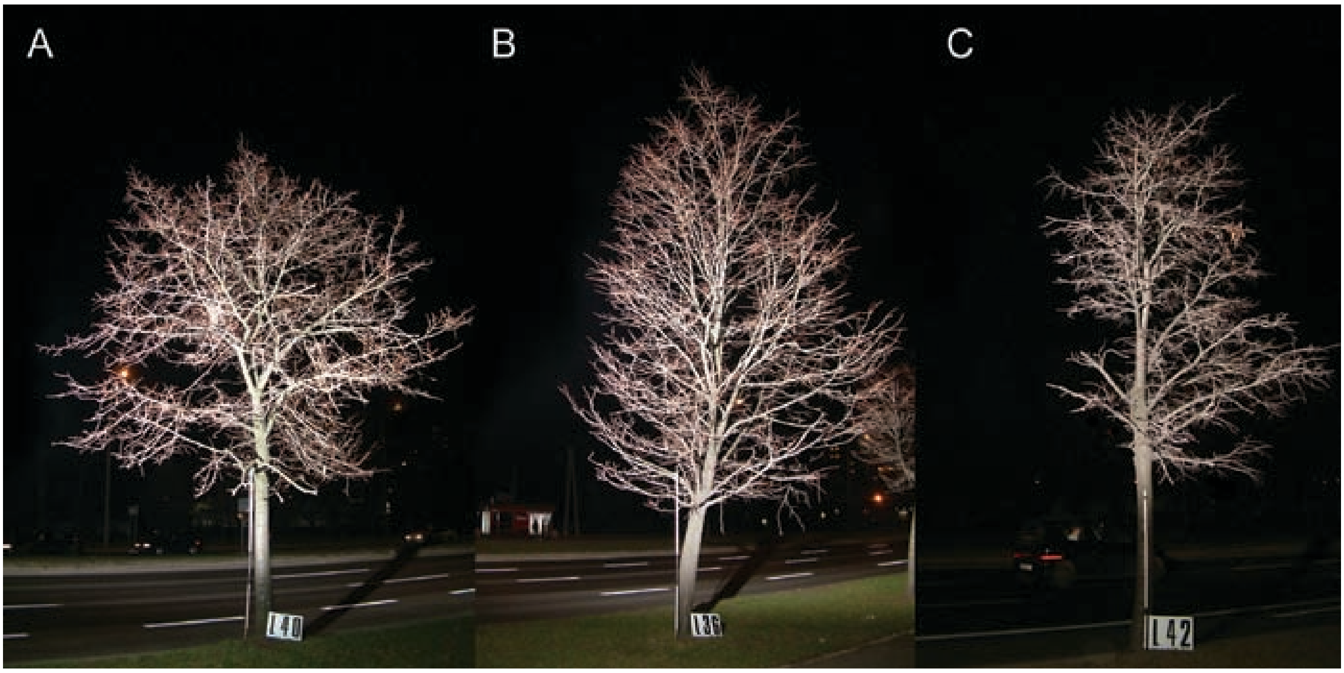


Fig. 14. Growing lime – A, and dying trees with restrained growth – B and C
(phot. M. Pstrągowska, 2008)

and 36), and some trees increased in size (e.g. limes no. 38, 39 and 40), which clearly shows different tolerance levels of individual trees to street habitat conditions (Fig. 14).

It is likely that individual trees that do not show expansion of crowns are in an initial state of dying back, as for young trees it is growth that is a natural process and not stagnation or even reduction in size. These trees are evidently dying back. Separation of the two categories of trees, living and dying back individuals, based on increment trends allowed to focus on plants that were growing vigorously. Some individuals from among studied trees turned out to be extraordinarily tolerant of excessive salinity and other negative effects of street environment. Undoubtedly limes no. 38 and 40 can be assigned to this group. Perhaps, facing worsening of the conditions of street habitats, we should search for single, most tolerant and vigorously growing individuals (genotypes) and propagate them. Not only new resistant species should be looked for nowadays, as suggested by Dirr (1976) and Roloff et al. (2009), but also single individuals which would allow for conservation in street habitats of various tree species, including native and popular Small-leaved limes.

Conclusions

1. Saline aerosol is one of the main ways of dispersal of de-icing salt.
2. High salt concentration on tree buds and shoots causes major growth anomalies resulting in the crown deformation and restrain growth of even young trees.
3. It is necessary to reduce the quantity of sodium chloride used in streets for de-icing.
4. Individual trees highly tolerant of salinity and other negative factors characteristic for degraded street habitats should be chosen, propagated and used for street and road greening.

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