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Effect of salinity stress on growth and macroelements uptake of four tree species

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Abstract: Woody plants grown near the roads are force-fed by salt and this has negative effect on their growth and decorative value. The aim of the presented study was to investigate the effects of salinity on growth and nutrient composition of four trees species often planted along the roads and streets in Poland. Two years old seedlings (bare root) of four tree species: *Acer negundo*, *A. platanoides*, *Quercus robur* and *Tilia cordata* were potted and grown outside under four soil salinity levels maintained by drenching plants with tap water containing 0.25, 0.5, 1.5, and 3.3g NaCl/L H_2O. Plant height, soil samples for electrical conductivity (EC) and pH determination as well as leaf samples for macroelements (N, P, K, Ca, Mg) content evaluation were collected after each growing season of two years of experiment. Electrical conductivity of the growing medium varied insignificantly between species, but salt concentration in the growing medium was distinctly higher in the upper than in the bottom part. Soil salinity had strong but variable effect on plant growth during the experiment. Only *Acer negundo* growth was not affected even by the highest concentration of NaCl solution. With increasing salinity of growing medium more Na^+ was taken by all species but the biggest amount of sodium ions was accumulated in the leaves of *Tilia cordata*, while the lowest in *Acer negundo*. Than potassium ions content decreased with increasing medium salinity only in the leaves of *Quercus robur* and *Tilia cordata*. In the leaves of *Acer platanoides* and *Tilia cordata* calcium concentration was decreased at increased salinity, in two other tested species amount of Ca^{2+} in the leaves was elevated. The main conclusion that can be drown is that *Acer negundo* is highly tolerant to salinity stress while *Acer platanoides* was the most sensitive among tested species

Additional key words: salinity resistance, salinity stress, nutrient uptake, ornamental trees

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Introduction

A high NaCl content is widespread and is often reported by many authors for arid and semi-arid regions (Greenway and Munns 1980). For northern hemisphere countries this problem seems to be less important, but on the other way, in these countries, use of great amounts of NaCl for winter road deicing is very common. Modern societies expect safe roads and highways even after the heavy snowstorm. Sodium chloride is used as the principal deicer because it is the most available and because it is relatively inexpensive. The social and economical benefits of NaCl deicing are evident, that is why environmental impacts are acceptable. Woody plants grown near the roads are force-fed by salt and this has negative effect on their growth and decorative value (Towsend 1980; Marosz 2001, 2004). Glycophytes generally achieve their best growth in non-saline conditions and growth reduction is observed as salinity increases.

Salinity effect on plants is complex and the injurious effect of soil salinity is linked with water deficit, mineral nutrition, stomatal behavior, carbon allocation, photosynthetic efficiency and ionic imbalance (Bohnert and Jensen 1996; Moghaieb et al. 2001). Nutrition deficiency or ion toxicity is often caused by the over dominance of specific ion (especially Na). Salinity with sodium chloride affects water ion transport processes in trees and this may change nutritional status level and ion balance (Lauchli and Epstein 1990). In this case many authors reported that in the saline soil conditions plants accumulated great amount of sodium ions, in association with low potassium ion content (Sehmer et al. 1995; Silberbush 2001; Loupassaki et al. 2002; Marosz 2004). Also calcium uptake in the saline soils is often disturbed. It is not the rule, but often calcium concentration in leaves of sensitive species decreased with increasing soil salinity, whereas in the resistant species Ca^{2+} content increased or remained unchanged (Francois 1982; Marosz 2004). Salinity dominated by Na^{+} salt not only reduces Ca^{2+} availability, but also Ca^{2+} transport and mobility to growing regions of the plant, which affect quality of both vegetative and reproductive organs (Rengel 1992). In this case higher calcium nutrition for plants grown under salinity stress is welcome and could reduce concentration of Na ions in the leaves (Kaya et al. 2003).

The experiment was designed to investigate the effects of salinity on growth and nutrient uptake of four trees often planted or recommended for planting along the roads and streets in Poland.

Materials and methods

Two years old seedlings (bare root) of four tree species: *Acer negundo* (ash-leaved maple), *A. platanoides* (norway maple), *Quercus robur* (penduncculate oak) and *Tilia cordata* (littleleaf linden) were purchased from a nursery and planted to containers (1.6 dm^3 volume for oak and 3 dm^3 volume for other species) with long-fibred sphagnum peat and sand (4:1 by volume) as a potting medium with pH 6.77. Plants were grown outside under automatically controlled overhead sprinklers irrigation. Three weeks after planting salinity treatments were started.

Four salinity levels were maintained by irrigating plants with tap water containing 0.25, 0.5, 1.5, and 3.3g NaCl/L H_2O. The electrical conductivity (EC) of the solutions was 1.0, 2.0, 3.5, and 6.5 $mS \cdot cm^{-1}$. For each oak plant 150 ml of salt solution and for other species 300 ml of salt solution was supplied 8 times with 7 days intervals. Together it gave 0.3, 0.6, 1.8, and 4 g pure NaCl for oak trees and double amount for maples and linden. Salt amount used for experiment was not so high, comparing to amount of chemical used for deicing streets in Warsaw where total salt use varied from 580 $g \cdot m^{-2}$ in the winter 2000/2001 to 1100 $g \cdot m^{-2}$ in the winter 2003/2004 – data obtained from Warsaw City Municipal Services (Zakład Oczyszczania Miasta ZOM – 2005). Control plants in the experiment were irrigated with the same amount of tap water of EC 0.5 $mS \cdot cm^{-1}$.

Plant height was evaluated in the end of the growing season. Soil samples for EC and pH determination were taken from each pot plant one week after the last salinization. Samples were taken from upper and bottom layers of the medium to monitor changes in pH and EC and salt leaching effect. EC and pH levels were measured by conductivity and pH meter (Multi-parameter analyzer, Eijkelkamp, Holland)

Leaf samples from each plant were taken at the end of August every year of study. Then, samples were oven-dried at 70°C and treated with mixture of HNO_3 and $HClO_4$. The concentration of K^{+}, Ca^{2+}, Mg^{2+} and Na^{+} were measured using atomic absorption spectrophotometry (PU 9100X Philips, Holland). Concentration of phosphorus was determined colorimetrically using vanadium-molybdate complex and nitrogen was determined using the Kjeldahl method with an automatic distillation system with H_3BO_3 (Kieltec, Tecator, Sweden).

The experiment encompassed 4 salt concentration treatments plus control and there were 4 replicates with 5 plants per replicate. The experiment was repeated in 2006. The data were analyzed statistically with ANOVA and are presented as means for two years. To establish significance of differences between means Duncan's Multiple Range Test was used.

Results

Salinity and pH changes in the growing medium

Electrical conductivity of the growing medium varied between species, and according to data from table 1, EC of the growing medium in the container was distinctly higher in the upper than in the bottom part. In the control plants irrigated with tap water EC of the upper and bottom part of the medium was, respectively, from 149.9 to 138.8 $mS \cdot cm^{-1}$ for ash-leaved maple and from 120 to 93.8 $mS \cdot cm^{-1}$ for *Quercus robur*. In combinations with NaCl solution, salinity of the medium in the upper and bottom part built up and was the highest when solution used for watering plants was 3.5 and 6.5 $mS \cdot cm^{-1}$. The highest salinity for upper and bottom part of the medium, respectively, 214 and 168.9 $mS \cdot cm^{-1}$ for *Tilia cordata*, as well as 204.1 and 188 $mS \cdot cm^{-1}$ for *Acer platanoides*, was obtained with the highest salinity treatment (Table 1).

Salinity had no effect on pH of the growing medium and was the same within the species irrespective of salinity treatment. In all tested trees pH was a little bit higher in the upper then bottom part of the growing medium (Table 2).

Table 1. Electrical conductivity (mS cm^{-1}) of growing medium solution in the end of experiment (means for two years of experiment)

EC treatment mS cm^{-1}	*Acer negundo*		*Acer platanoides*		*Quercus robur*		*Tilia cordata*	
	upper part	bottom part	upper part	bottom part	upper part	bottom part	upper part	bottom part
Control	149.9a*	138.8a	137.1a	109.2a	120.0a	93.8a	134.7a	94.7a
1.0	153.2a	142.1ab	148.4ab	128.0a	128.1a	104.0b	136.1a	107.3ab
2.0	174.6b	142.4ab	154.2b	154.1b	128.6a	104.4b	137.6a	121.8b
3.5	183.0c	147.2b	199.4c	173.9c	129.9a	110.1b	139.1a	125.7b
6.5	184.2c	149.8b	204.1c	188.0c	145.5b	144.0c	214.0b	168.9c

*means within the column denoted by the same letter do not differ significantly at $P = 0.05$ according to Duncan's multiple range test

Table 2. pH of growing medium in the end of experiment (means for two years of the study)

EC treatment mS cm^{-1}	*Acer negundo*		*Acer platanoides*		*Quercus robur*		*Tilia cordata*	
	upper part	bottom part	upper part	bottom part	upper part	bottom part	upper part	bottom part
Control	8.7a*	8.0a	8.4a	7.4a	8.5a	7.5a	8.5a	7.5a
1.0	8.7a	8.0a	8.4a	7.5a	8.5a	7.5a	8.4a	7.5a
2.0	8.7a	8.0a	8.4a	7.4a	8.4a	7.8a	8.4a	7.5a
3.5	8.7a	8.2a	8.4a	7.6a	8.4a	7.9a	8.4a	7.8a
6.5	8.5a	8.4a	8.4a	7.8a	8.5a	7.9a	8.4a	7.6a

*means within the column denoted by the same letter do not differ significantly at $P = 0.05$ according to Duncan's multiple range test

Plant growth and salt tolerance

Significant differences among species in salt tolerance were found using two-year tree seedlings. Soil salinity had strong but variable effect on plant growth during the experiment. Growth of *Acer negundo* was not affected even by the highest concentration of NaCl solution (EC 6.5 mS·cm^{-1}) used for irrigation. Length of annual increments was similar in all treatments (Table 3). Growth of *Acer platanoides* decreased strongly with increasing soil salinity. Height of trees grown under the highest salt concentration was 20.3 cm shorter then control. Salinizations had also negative effect on growth of *Quercus robur* and *Tilia cordata* where plants under the highest concentration of NaCl solution were lower then control ones, respectively, by 4.7 cm and 6.4 cm. It should be stressed that visible effects of salinity (leaf-injury symptoms) were noted on all species with exception of *Acer negundo*. The earliest and most severe symptoms have been observed on *Acer platanoides* plants grown under two highest concentration of NaCl. Leaf-edge burning was first noted on this species after fourth salinization. In the end of the experiment severe leaf dropping was also noted and only the youngest leaves had no visible effect of leaf-injury caused by salinity. Another species with high leaf-injury effect was *Tilia cordata* but it occurred only under the highest solution of NaCl (EC 6.5 mS·cm^{-1}) used for irrigation. On *Quercus robur* leaf-edge burning was noticeable from time to time.

Table 3. Length of annual increments (in cm) of trees grown under salinity stress (means for two years of experiment)

EC treatment mS cm^{-1}	*Acer negundo*	*Acer platanoides*	*Quercus robur*	*Tilia cordata*
Control	35.1a*	51.3c	11.4c	28.7b
1.0	33.1a	49.5bc	10,1c	26.9b
2.0	34.5a	45.7b	8.1ab	26.3b
3.5	34.7a	42.6b	7.6ab	22.8a
6.5	34.9a	31.1a	6.7a	22.3a

*means within the column denoted by the same letter do not differ significantly at $P = 0.05$ according to Duncan's multiple range test

Nutrients uptake

Macroelements content in leaves was affected by EC level of NaCl solution and differed between species. Year of cultivation had significant effect on ions uptake in all tested trees. Generally, in 2006 higher uptake of potassium was observed in all species as well as more Ca^{2+} and Na^{+} were accumulated by leaves of both maple species. Uptake of other ions in 2005 and 2006 was specific to the species and is shown in Tables 4–7. Significant interaction between year of cultivation and EC of NaCl solution was noted for sodium ion uptake by *Tilia cordata* (Table 7).

With increasing growing medium salinity more Na^{+} was taken by all species but the biggest amount of sodium ions was accumulated in the leaves of *Tilia cordata* and the lowest in *Acer negundo* (Tables 4 and 7). Potassium ions content decreased with increasing medium salinity only in the leaves of *Quercus robur* and *Tilia cordata*, in the leaves of *Acer* species it remained unchanged. Calcium was another ion which uptake by trees was disturbed (Tables 4–7). The highest level of this macroelement was noted in leaves of

Table 4. Macroelements leaf content of *Acer negundo* (ash-leaved maple) grown at different soil salinity (in % of dry weight)

Treatment EC level (mS cm^{-1})	N	P	K	Ca	Mg	Na
0.5 Control	1.48a	0.14a	1.04a	2.18a	0.39a	0.16a
1.0	1.41a	0.13a	0.93a	2.21a	0.47a	0.2b
2.0	1.42a	0.14a	0.93a	2.22a	0.45a	0.22b
3.5	1.46a	0.14a	1.02a	2.48a	0.47a	0.21b
6.5	1.39a	0.14a	1.05a	2.52a	0.49a	0.23b
Year of cultivation						
2005	1.41a	0.13a	0.54a	1.76a	0.47a	0.19a
2006	1.46a	0.14a	1.44b	2.88b	0.45a	0.22b
Significance level						
EC	ns	ns	ns	ns	ns	ns
Year of cultivation	ns	ns	**	**	ns	ns
EC × year of cultivation	ns	ns	ns	ns	ns	ns

ns – non significant
*means followed with the same letter, in each column do not differ significantly at $P = 0.05$ according to Duncan's multiple range test

Table 5. Macroelements leaf content of *Acer platanoides* (Norway maple) grown at different soil salinity (in % of dry weight)

Treatment EC level (mS cm^{-1})	N	P	K	Ca	Mg	Na
0.5 Control	1.3a	0.11a	0.78a	1.84b	0.31a	0.43a
1.0	1.48a	0.22a	0.67a	1.97b	0.3a	0.61b
2.0	1.46a	0.22a	0.69a	1.88b	0.33a	0.59b
3.5	1.28a	0.12a	0.76a	1.28a	0.31a	0.64b
6.5	1.47a	0.13a	0.77a	1.25a	0.3a	0.77bc
Year of cultivation						
2005	1.24a	0.15a	0.46a	1.58a	0.28a	0.51a
2006	1.56b	0.18a	1.0b	2.04b	0.35b	0.75b
Significance level						
EC	ns	ns	ns	**	ns	**
Year of cultivation	**	ns	**	**	**	**
EC × year of cultivation	ns	ns	ns	ns	ns	ns

ns – non significant
*means followed with the same letter, in each column do not differ significantly at $P = 0.05$ according to Duncan's multiple range test
**significant at $P = 0.05$

Table 6. Macroelements leaf content of *Quercus robur* (penndunculate oak) grown at different soil salinity (in % of dry weight)

Treatment EC level (mS cm^{-1})	N	P	K	Ca	Mg	Na
0.5 Control	1.3a	0.14a	0.7c	1.03a	0.19a	0.32a
1.0	1.24a	0.14a	0.66bc	1.1a	0.18a	0.37ab
2.0	1.54a	0.15a	0.59ab	1.1a	0.18a	0.38ab
3.5	1.41a	0.17a	0.59ab	1.25ab	0.19a	0.4bc
6.5	1.31a	0.15a	0.57a	1.5b	0.24b	0.47c
Year of cultivation						
2005	1.31a	0.13a	0.55a	1.2a	0.16a	0.41a
2006	1.41a	0.17b	0.7b	1.18a	0.23b	0.37a
Significance level						
EC	ns	ns	**	ns	ns	**
Year of cultivation	ns	**	**	ns	**	ns
EC × year of cultivation	ns	ns	ns	ns	ns	ns

ns – non significant
*means followed with the same letter, in each column do not differ significantly at $P = 0.05$ according to Duncan's multiple range test
**significant at $P = 0.05$

Table 7. Macroelements leaf content of *Tilia cordata* (littleleaf linden) grown at different soil salinity (in % of dry weight)

Treatment EC level (mS cm^{-1})	N	P	K	Ca	Mg	Na
0.5 Control	1.44a	0.18a	0.98c	1.62b	0.29ab	0.36a
1.0	1.38a	0.26a	0.8abc	1.75b	0.27a	0.41a
2.0	1.35a	0.23a	0.82bc	1.64b	0.29ab	0.53b
3.5	1.42a	0.22a	0.74ab	1.61b	0.28ab	1.26c
6.5	1.47a	0.22a	0.58a	1.47a	0.32b	1.41c
Year of cultivation						
2005	1.22a	0.19a	0.66a	1.65a	0.24a	1.04b
2006	1.6b	0.14a	0.91b	1.59a	0.33b	0.56a
Significance level						
EC	ns	ns	ns	**	ns	**
Year of cultivation	**	ns	**	ns	**	**
EC × year of cultivation	ns	ns	ns	ns	ns	**

ns – non significant
*means followed with the same letter, in each column do not differ significantly at $P = 0.05$ according to Duncan's multiple range test
**significant at $P = 0.05$

ash-leaved maple and with increasing growing medium salinity also calcium uptake increased. The same pattern can be defined for pendunculate oak. Calcium concentration decreased with increasing salinity in the leaves of Norway maple *Acer platanoides* (Table 5), and in the leaves of littleleaf linden but only in the highest salinity level where calcium content was at the lowest level – 1.47% of dry weight (Table 7).

Uptake of other macroelements such as nitrogen, phosphorus and magnesium was not affected by EC level of growing medium (Tables 4–7).

Discussion

Ornamental plants, especially trees and shrubs planted near roads and streets can not be evaluated in terms of growth alone and the overall appearance must be also considered. Some authors suggested that appearance and survival should be ultimate criteria for planting plants in such places (Towsend 1980). This author observed severe leaf-injury on *Conrus florida* and *Platanus orientalis* with NaCl solution 4500 and 7000 ppm (6 and 12 mS·cm^{-1}, respectively). Author's own observation from another study indicates that leaf injures at such level of soil salinity occur also on *Cotoneaster* 'Ursynów' and *Spiraea* 'Grefsheim', resulting ultimately in plants death (Marosz 2001). In the present experiment leaf injuries were noted on *Acer platanoides* (the most evident), *Quercus robur* and *Tilia cordata*. Oak leaf damages were also evident in the Towsend's (1980) experiment after two weeks when seedlings leafed out, but after three weeks at two highest concentration of NaCl, foliar injury of this species did not increase. Many scientific papers confirm that leaf chlorosis, necrosis and dropping are associated with salinity (Alam et al. 2002; Francois 1982; Marosz 2001).

In addition to leaf-damage and defoliation, high soil salinity causes strong growth reduction and mortality of plants (Francois and Clark 1978; Loupassaki et al. 2002; Marosz 2004; Skimina 1980). The strongest reduction of growth was observed in *Acer platanoides* and *Quercus robur*. Less evident but statistically significant effect was noted for *Tilia cordata*. Only growth of ash-lived maple was not affected by salt treatment. Results of many experiments on essential elements related to salt treatment are inconsistent and often conflicting. Many authors suggested that under any set of conditions each species may respond to salinity in a different way (Shaybany and Kashirad 1978; Towsend 1980; Alam et al. 2002; Loupassaki et al. 2002; Marosz 2004).

Leaf macroelement content in tested species needs further explanation. High concentration of sodium ions with increasing salinity of the medium was observed in leaves of *Acer platanoides*, *Quercus robur* and *Tilia cordata*, but only for *Quercus* and *Tilia* low concentration of potassium indicating an apparent antagonism between K^+ and Na^+ was noted, which is confirmed by many other studies (Gratam and Grive 1999; Alam et al. 2002). Results of earlier research are similar. Howes Keiffer and Ungar (1997) found that *Hordeum*, *Spergularia* and *Suaeda* plants accumulated more Na^+ in shoots and roots instead of K^+. This could be explained by the fact that Na ions are used for less specific roles such as vacuolar osmotic adjustment instead of K^+ (Yeo 1983). Increasing concentration of Na ions in the pendunculate oak leaves was documented also by Sehmer et al. (1995) For Norway maple high concentration of Na^+ showed to be very toxic, resulting in severe injury and dropping of leaves and strong growth reduction, but potassium ion content in the leaves of this species remained unchanged. Results obtained in this study confirmed assumption that this tree is very susceptibility for soil salinity (Borowski and Latocha 2006). There was no difference in nutrient uptake and growth, irrespective of medium salinity level, in *Acer negundo*. It is possible that salt tolerant species may be able to compensate for increases or decreases in essential nutrients whereas other species may not and these two *Acer* species are good example of that.

Calcium uptake by plants is often disturbed in saline soils (Francois 1982; Alam et al. 2001; Kaya et al. 2003; Marosz 2004). Francois (1982) observed that calcium concentration in the leaves of three sensitive species decreased with increasing salinity, while in five more tolerant species it increased or remained unchanged. Similar results were presented by Marosz (2004), where more Ca^{2+} was taken by *Cotoneaster horizontalis*, *Potentilla fruticosa* 'Longacre' and *Spiraea* 'Grefsheim'. Only in the leaves of *Cotoneaster* 'Ursynów' – a plant sensitive to salinity – Ca^{2+} content greatly decreased with increasing salinity. Results from the presented study confirm these findings. Sensitive species, like *Acer platanoides* and *Tilia cordata*, in the saline medium accumulated less Ca^{2+} whereas *Acer negundo* and *Quercus robur* more.

Adaptation of tested tree species to salinity was different. *Acer platanoides*, and *Tilia cordata* took up great amount of sodium ions and this had negative effect on growth and general appearance, most evident on *Acer platanoides*. Sodium uptake of *Acer negundo* was similar in all salinity treatments and was on the low level comparing to other species.

Conclusions

1. *Acer negundo* can be classified as a species highly tolerant to salinity stress, and this tree can be planted near the main roads and streets. The highest medium salinity had no negative effect on growth and decorative value of this species.
2. *Acer platanoides* was the most sensitive tree among tested species, also *Tilia cordata* prove sensitive to salinity stress. Therefore, these trees should not be recommended for planting along the main roads and streets with heavy traffic.
3. Nutrients uptake differs between species. With increasing soil salinity more sodium ions was observed in all tested plants. In addition potassium ions content decreased in *Quercus robur* and *Tilia cordata*. More calcium ions were accumulated by *Acer negundo* and *Quercus robur* grown under high salinity level.

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