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Soil pH, electrical conductivity values and roadside leaf sodium concentration at three sites in central Poland

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Abstract: Sodium chloride is the most often used chemical to malt ice and snow on the roads and has negative effects on the roadside environment. The main is soil erosion, changes in mineral composition of the soil and negative impact of the growth of trees. This study described differences in electrical conductivity values in soil with increasing distance from the road. Leaf sodium contents in roadside trees have been determined to assess the uptake of this element by plants. Soil samples for EC (electrical conductivity) determination were collected in the spring and autumn 2009 and 2010 from the roadside environment every 1m started at 2m to 11m from the road edge, and every year at the same place. Leaf sample for sodium content were collected in the end of August 2009 and 2010 from *Acer platanoides*, *Acer pseudoplatanus*, *Tilia cordata* and *Fraxinus excelsior*, every year at the same trees. For comparison, samples of the leaves were also collected from trees grown in the park in Skierniewice, were no salting during the winters is provided. The composition of roadside salinity varies, mostly according to the roads, but generally, at the studied roads, the EC of the soil solution followed an exponential-like decrease with distance from the road curb, reaching background levels at 7 to 10 m distance. The exponential-like EC decrease seems to be strongly slowed at 5 m distance from the road curb. Very important information is that the level of EC in the upper layer of the soil during the season decreases rapidly. Trees grown on the roadside accumulated considerable amount of sodium ions in their leaves helping to neutralize the excess of sodium in soil. However, this had negative effect on their growth. *Acer platanoides* and *Tilia corada* uptake the greatest amount of sodium ions in comparison to the same species grown in the park. Less amount of sodium ion were noted in the leaf sample of *Acer peseudoplatanus* and *Fraxinus excelsior*. Soil salinity near the studied roads had any visual effect on the trees.

Additional key words: leaf sodium accumulation, soil electric conductivity, soil salinity, roadside trees, roadside environment

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Introduction

Sodicity-induced soil degradation is a major environmental constraint with severe negative impacts on agricultural productivity and sustainability in arid and semiarid regions. In Poland this problem is less common. However, only in December 2010 on roads and streets almost 200 thousand tons of NaCl (alone and mixed with sand) were applied to maintain safe driving conditions (press data of General Directorate of National Roads and Motorways in Polad). The use of NaCl results in increased soil salinity along the roads and is the main reason to damage roadside vegetation, and also contaminate of groundwater and surface waters (Green and Cresser 2008). There are several factors regulating the airborne spread and deposition of salt, such as traffic characteristics, road type and surface condition, amount of salt application and weather conditions. Splash and spray emanate from the tyre-road interface, and are hence due to traffic. Splash is generally deposited in the proximity of the road, but salt spray can be transported further by wind (Blomqvist and Johansson 1999).

Road side soils and plants, especially trees and shrubs, are exposed for decades to road salt. As an important category of salt-affected soils, sodic soils exhibit unique structural problems as a result of certain physical processes (slaking, swelling, dispersion of clay, increase organic colloid mobility and alter the structure of the soil) and specific conditions like surface crusting (Shainberg and Letey 1984; Norrström and Bergstedt 2001; Qadir and Schubert 2002). In addition, changes in the proportions of soil solution and exchangeable ions lead to osmotic and ion-specific effects together with imbalances in plant nutrition, which may range from deficiencies of several nutrients to high levels of Na^+ (Kaya et al. 2003; Marosz 2004; Marosz and Nowak 2008). Sodic and saline-sodic soils are generally described in terms of the relative amounts of Na^+ in the soil solution or on the cation exchange complex, given the accompanying levels of salinity. Therefore, soil sodicity represents the combined effects of salinity is often measured by electrical conductivity of the soil (EC) or soluble Na^+ concentration (Qadir et al. 2007)

Woody plants grown near the roads are force-fed by salt and this has a negative effect on their growth and decorative value (Marosz 2004). However, impact on roadside vegetation due to salt spray on aboveground tree parts or to salt uptake by roots also depends on where the salt is deposited, soil type and its ability to transport and retain water (Fostad and Pedersen 2000).

This research is focused on salinity and pH changes in the soil near the main roads in central Poland. Also sodium content in the leaves of trees that are grown along this roads is presented and discussed with earlier research leaded in control conditions.

Material and methods

Characteristic of the studied road site. The study site was located on three main roads in central Poland. First was the two line road between Zwoleń–Puławy, about 10 km from Puławy – 51°23’N 21°44’E. The site has an annual average daily traffic volume of about 3800 vehicles. The roadside soil at the site comprised of good sandy-loam soil (fine-grained). The trees begin at 8 m from the road (Fig. 1), while closer to the road the vegetation consists of grass that is cut once a year during the late summer. Trees are: *Acer pseudoplatanus, Tlilia cordata,* and newly planted *Sorbus aucuparia* (unfortunately already dead). Second was located on the two line road nr 50 between Mszczonów and Grójec, about 15 km from Grójec – 51°54’N 20°42’E. The site has an annual average daily traffic volume of about 3500 vehicles (mostly trucks). The roadside soil at the site comprised wave-washed sandy-loam soil (medium-grained). The trees begin at 5 m from the road. Trees are: *Fraxinus excelsior, Tilia coadata,* (not often), few years ago new trees of *Sorbus aucuparia* were planted on the roadside but now all are dead. Third site was located on four line road nr 8 between Mszczonów and Rawa Mazowiecka, about 10 km from Rawa Mazowiecka – 51°50’N 20°21’E. The site has an annual average daily traffic volume of about 9500 vehicles. The roadside environment at the site comprised wave-washed sandy soil (medium-grained). The trees begin at 5 m from the road. Trees are: *Tilia cordata,* and *Acer platanoides* but this is not often seen.

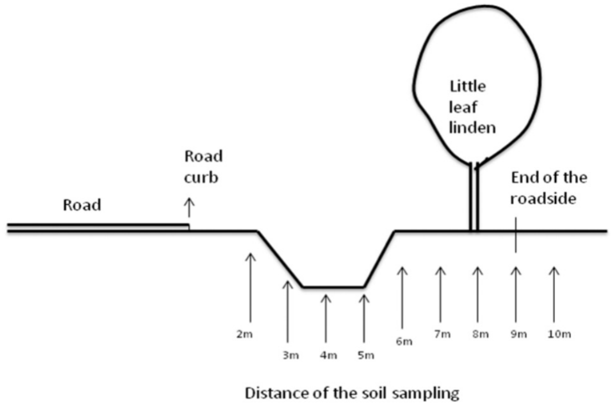

Fig. 1. Studied transects on road Zwoleń-Puławy and Rawa Mazowiecka-Mszczonów across the roadside environment interface with sampling distances indicated

On all sites closest to the roads, within 1 m distance, the natural soil layers are overlain by crushed rock from the road reinforcement layer. In this case that was impossible to take the sample from that site.

Soil sampling. Soil samples for EC (electrical conductivity) and pH determinations were taken in spring (2.04) and in the autumn (15.11) 2009 and 2010. Samples collection started at 2m from the road curb and was ending at 12 m from road curb (Fig. 1 and 2). Each time then samples was taken from the three different depth of the soil: 10, 20 and 30 cm. EC and pH levels were measured using the multi-parameter analyzer (Eijkelkamp – Agrisearch Equipment, Netherlands), immediately after the samples were supply to the laboratory.

Plant material. Leaf sample from two trees (for each species) grown on the roadside were taken at the end of August every year of the study. For comparison of sodium accumulation, leaf sample were also collected from trees grown in Skierniewice Park and

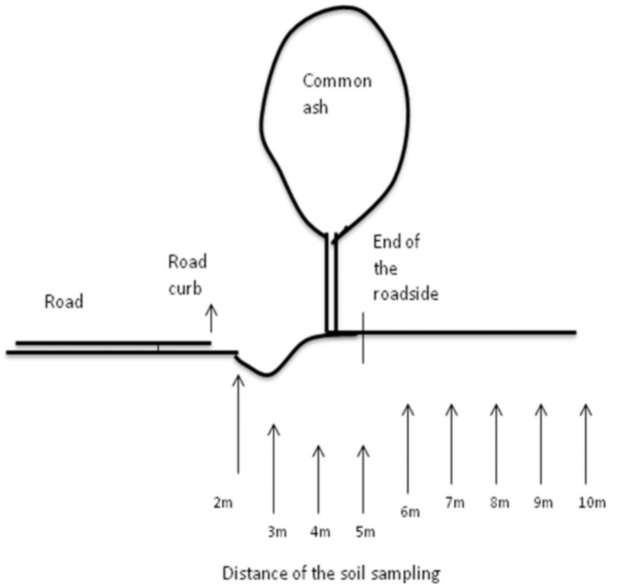

Fig. 2. Studied transects on road Gójec-Mszczonów across the roadside environment interface with sampling distances indicated

these samples were treated as control. From one tree, two leaf samples were collected from the low part of the crown. In total, the survey was intended for four separate samples. Than samples were oven-dried at 70°C and treated with mixture of HNO_3. The concentration of Na were measured using automatic absorption spectrophotometery (PU 9100X Philips).

Statistical analysis. The data for EC, pH and Na leaf content were analyzed statistically with ANOVA and are presented as means for two years. The experiment was completely randomized with ten replicates (every soil and leaves samples was treated as a replicate). To establish significance of differences between means Duncan's Multiple Range Test was used.

Results

Salinity and pH changes in the soil

The composition of road salts varies, mostly according to the roads, but generally, at the studied roads, the EC of the soil solution followed an exponential-like decrease with distance from the road curb, reaching background levels at 7 to 10 m distance. The exponential-like EC decrease seems to be slowed at 5 m distance (Fig. 4–6). This might be the effect of the road-parallel trench (Fig. 1 and 2), which collects runoff water and dissolved salts.

The lowest level of EC in the soil was recorded in samples taken from the roadside of the road Zwoleń-Pułway. At a depth of 10 cm, electrical conductivity in spring 2010 was 269 mS·cm^{-1}. However, the level of salinity increased with depth of soil sampling, so that at a depth of 30 cm EC of the soil reached 300 mS·cm^{-1}. Very important information is that the level of EC in the soil during the season decreases rapidly and in autumn 2010 the EC of soil solution at depth of 10 cm in the vicinity of the road (2–5 m from the road curb) was 42 to 110 mS·cm^{-1} lower than in the spring (Fig. 3). Therefore salt during the year was eluted to the deeper soil layers fairly quickly, so that at depth of 30 cm salinity EC lewvel was higher in the autumn than in the spring (Fig. 3). Soil EC along the two other roads with higher traffic volume was higher and in the immediate vicinity of the road at a depth of 10 cm contributed more than 300 mS·cm^{-1}. Analysis of samples from the deeper layers of soil (20 and 30 cm) revealed that measurements of EC in the spring did not differ significantly from measurements made in the autumn (Fig. 4 and 5).

Analysis of soil pH shows that the use of salt for snow removal from road surface significantly affects the change of soil pH from a slightly acidic to alkaline.

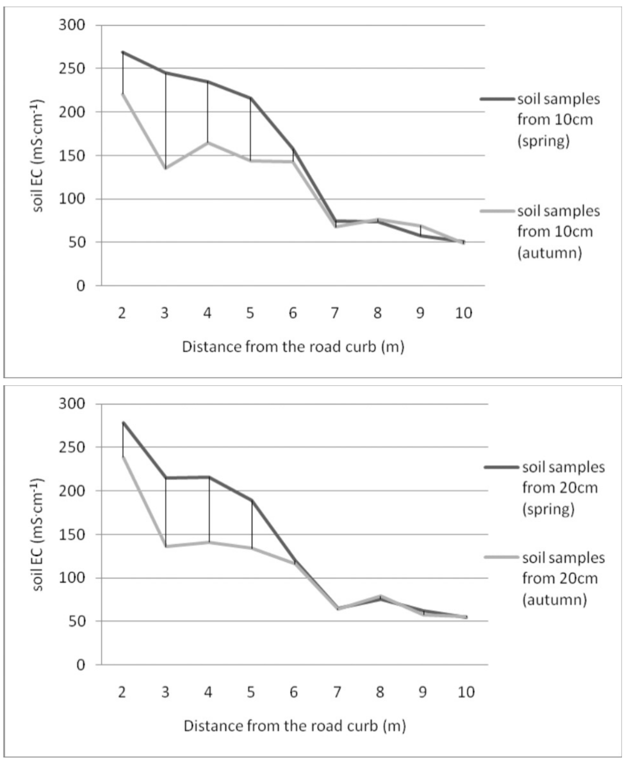

Fig. 3. Changes in the soil EC on the road Zwoleń-Puławy according to the season, distance from the road curb and the depth of the soil sample

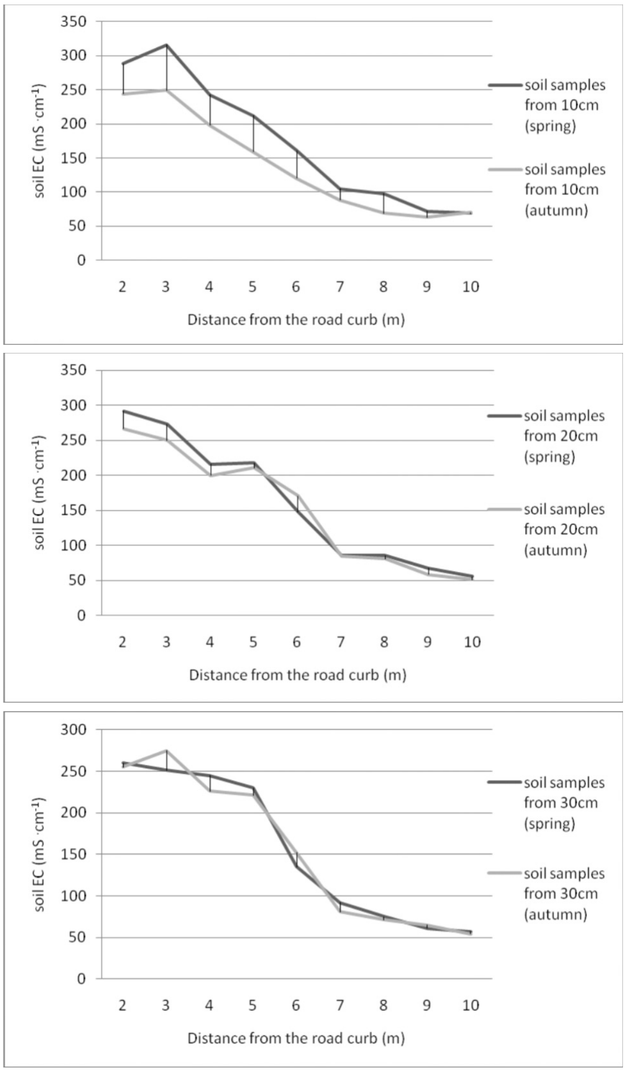

Fig. 4. Changes in the soil EC on the road Grójec-Mszczonów according to the season, distance from the road curb and the depth of the soil sample

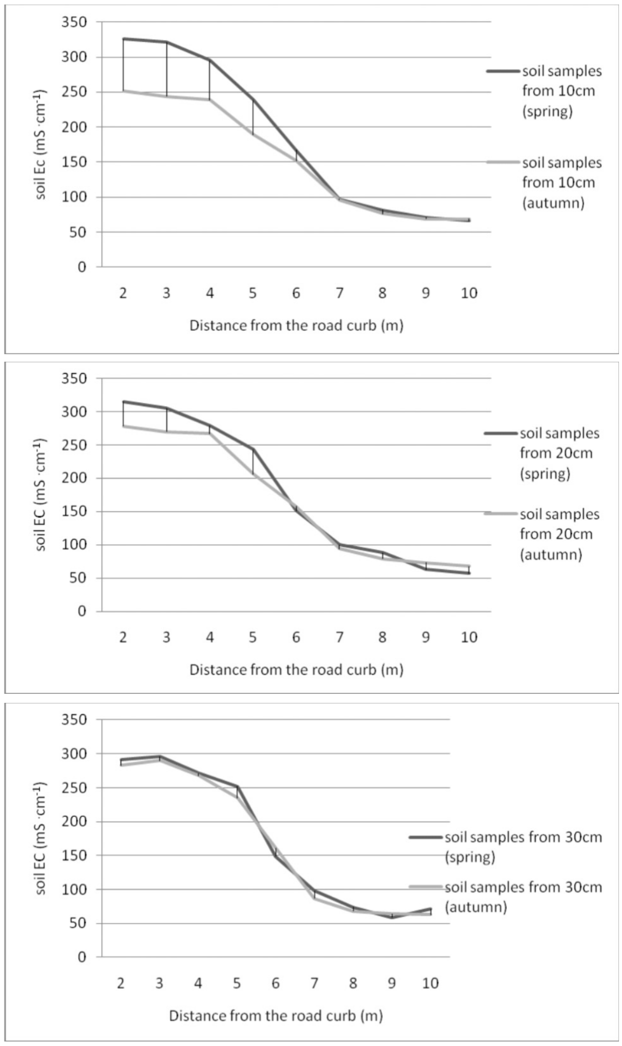

Fig. 5. Changes in the soil EC on the road Rawa Mazowiecka-Mszczonów according to the season, distance from the road curb and the depth of the soil sample

Results from Table 1 shows that the highest soil pH is near the road curb, within 2 m distance. Then gradually decreases with increasing distance from the road and coincides exactly with the value of EC. These relationships were observed at all sites selecting for experiment (Table 1).

Leaf Na content

The results indicate that the use of sodium chloride for de-icing roadways affects of sodium ions downloading by the trees grown along the road and streets. The biggest amount of Na^{+} was accumulated in the leaves of *Tilia cordata* grown along the road no 12 and 50. Data from year 2009 and 2010 are similar. Trees of that species grown in Skierniewice city park had over four time less content of sodium ion then specimen from roadside environment (Table 2). Less amount of sodium ion was noted in *Acer platanoides*, but still significantly higher compared to trees grown in park. The lowest sodium accumulation was noted in the leaves of *Acer pseudoplatanus* and *Fraxinus*

Table 1. pH of the soil at the experimental site along the three road in central Poland, soil samples from 10 cm depth

Localization/ Road	Distance of the road curb (m)								
	2	3	4	5	6	7	8	9	10
Rawa Mazowiceka–Mszczonów	8.51d*	7.47c	7.29c	6.88b	6.86b	5.6a	5.49a	5.8a	5.19a
Zwoleń–Puławy	8.53d	7.43c	7.4c	6.74b	6.5b	5.83a	5.51a	5.74a	5.28a
Gójec–Mszczonów	8.62e	7.61d	7.8d	6.9c	6.44b	6.2ab	6.1ab	5.91a	5.67a

*means followed with the same letter within the same road number do not differ significantly according to Duncans Mulitple Rage test at p = 0.05.

Table 2. Sodium content in the leaves of mature trees grown on the roadside environment along the three road in central Poland (mg kg $^{-1}$ d.w.)

Trees localization	*Acer platanoides*		*Acer pseudoplatanus*		*Fraxinus excelsior*		*Tilia cordata*	
	2009	2010	2009	2010	2009	2010	2009	2010
Rawa Mazowiceka- Mszczonów	–	–	0.46b	0.57c	0.33b	0.48b	–	–
Zwoleń-Puławy	0.93b*	1.15b	0.32ab	0.39b	–	–	1.63b	1.78b
Gójec-Mszczonów	1.18b	1.29b	–	–	0.56c	0.62c	1.85c	1.81b
Control Skierniewice Park	0.15a	0.22a	0.23ab	0.25a	0.16a	0.12a	0.42a	0.37a

**means followed with the same letter within the same year and the species do not differ significantly according to Duncans Mulitple Rage test at p = 0,05.

exclelsior (Table 2). In this two species differences in amount of sodium accumulation according to road type were noted. *Acer pseudoplatanus* from road no 8 location and *Fraxinus excelsior* from road no 50 location uptake more sodium ions than trees grown in other location (Table 2). It is associated with higher rates and greater use of sodium chloride and therefore the higher content of sodium in the soil near this roads was observed. These roads have also a greater traffic volume. Although soil salinity on the roadside in designated locations was quite large, and the trees draw a significant amount of sodium on the leaves had not been any damage caused by excessive accumulation of this element.

Discussion

The roadside environment is very heterogeneous and contains various soil and vegetation types within a short distance. Therefore comparing the three locations very distant from each other might be confusing. Norrström and Jacks (1998) found that road salt application had led to a Na saturation of up to 27% at the exchange complex of roadside soils, which in turn had significant impacts on soil colloidal behavior and heavy metal mobility. In the presented experiment is clearly shown that salinity rapidly decreases with distance from the road. This confirmed by other authors. Lundmark and Jansson (2008) underlined that differences with distance from the road were clearly shown in all measurements even with the soil temperature during the winter period which was generally lower closest to the road and showed less fluctuation compared with the variation in soil temperature in the forest soil. The first meters from the road received a high amount of salt deposition, snow from plugging and road runoff. This is also the region of highest uncertainty, both due to the complex situation and due to lack of deposition measurements close to the road. The redistribution of sodium chloride in both soil and snow is difficult to capture in both observations and modeling in this complex environment close to the road. There were no significant differences between the soil EC measurements at 2 and 3, 4, and 5 m that could confirm the difference in salt deposition (Lundmark and Jansson 2008). Results presented by Cunningham et al. (2008) support hypothesis that salt cations would show accumulation near impervious surfaces and decline with distance. Among all samples, Na^+ and Mg^{2+} levels were higher near paved and road surfaces than far from them. The composition of road salts varies, but generally NaCl constitutes the main ingredient. At the studied highway, the NH_4NO_3-extractable Na contents followed an exponential-like decrease with distance from the road curb, reaching background levels at 5 to 10 m distance. Which is with agreement with results presented in the article. The exponential-like Na decrease seems to be slowed at 3.7 m distance. This might be the effect of the road-parallel trench, which collects runoff water and dissolved salts. The trends observed for Na were confirmed by the electrical conductivity, which is a surrogate for the salt concentration in solution Lundmark and Jansson (2008). Soil pH is a very important factor that influences availability of micronutrients for plants. The optimal soil pH value for plant nutrition is 6.5 and if it exceeds 7.5, the uptake of important elements, such as Zn, P, Mn, Cu, and Fe, is hampered (Adams and Early 2004). The use of sodium chloride for road deicing resulted in increased soil alkalinity (Table 1). This is supported by Bach et al. (2007) where pH of soil under *Tilia ×europaea* 'Pallida' along main street in Częstochowa ranged from 7,4 to 8,6 and EC from 0,2 to 0,5 mS · cm^2.

McBean and Al-Nassri (1987) reported that deposition from the splash transport mechanism in the region close to the road can result in an uneven distribution of salt in the roadside environment. Splash could also to some extent be deposited on the hard shoulder, and the salt would then accompany the runoff water off the road. Salt spray can be transported longer distances by wind. Blomqvist and Johansson (1999) showed that some up to 100 m distance. However, it is not a significant amount of salt and it is quickly neutralizated in the environment.

Sodium leaf content for trees from roadside environment is little higher than for this grown in the container, in laboratory experiment. Such differences are observed for *A. platanoides* and *T. cordata* grown under the highest sodium chloride treatment of EC solution 6.5 mS·cm^{-1} (Marosz i Nowak 2008). On plants grown in the container severe leaf burning and dropping were seen in comparison to specimen from natural site were no damage was noted. It must be said that the trees grown in containers were two years old seedlings and thus their response to salinity may be more pronounced compared with the mature trees from roadside habitats. However, Towsend (1980) observed severe leaf-injury on *Platanus orientalis* and *Cornus florida* grown along the highway. High Na^+ content in leaves connected with increasing soil or growing medium salinity is also reported by other authors. Mousavi et al (2008) noted that olive trees grown under 160 mM of NaCl had accumulated more Na^+ than other macronutrients. Increasing concentration of Na ions in the leaves of *Quercus robur* was documented also by Sehmer et al. (1995). Also ornamental shrubs such a *Cotoneaster horizontalis* and *Cotoneaster* 'Ursynów' downloaded significant amount of sodium under high soil salinity level (Marosz 2004). Lasted amount of Na^+ within respondent trees received *Acer pseudoplatanus* and *Fraxinus excelsior,* although significantly more than specimens from park.

Conclusion

Roadside soil pollution by sodium chloride is highly heterogeneous and – under the studied conditions (3500 -9500 vehicles per day) – most noticeable only in the immediate roadside zone, i.e. within 5 m from the road curb. Farther from the road the soil EC rapidly decreases. Trees of *Acer platanoides*, *A. pseudoplatanus*, *Fraxinus excelsior*, and *Tilia cordata* accumulated considerable amount of sodium ions in their leaves.

References

Adams C.R., Early M.P. 2004. Principles of horticulture. Oxford: Elsevier.

Bach A., Frazik-Adamczyk M., Pawłowska B., Pniak M., 2007. The effect of urban conditio on heath status of common lime (Tilia ×europaea 'Pallida') ot the Virgin Mary Avenue in Częstochowa. Roczniki Akademii Rolniczej w Poznaniu 383 seria Ogrodnictwo 41: 11–16 (in polish).

Blomqvist G., Johansson, E.L. 1999. Airborne spreading and deposition of de-icing salt – a case study. The Science of the Total Environment, 235: 161–168.

Cunningham M.A., Snyder E., Yonkin D., Ross M., Elsen T. 2008. Accumulation of deicing salts in soils in an urban environment. Urban Ecosystems 11: 17–31.

Fostad O., Pedersen, P.A. 2000. Container-grown tree seedling responses to sodium chloride applications in different substrates. Environmental Pollution, 109: 203– 210.

Green S.M., Cresser M.S. 2008. Nitrogen cycle disruption through the application of de-icing salts on upland highways. Water, Air and Soil Pollution 188:139–153.

Lundmark A., Jansson P.E. 2008. Estimating the fate of de-icing salt in a roadside environment by combining modelling and field observations. Water, Air and Soil Pollution 195: 215–232.

Kaya C., Ak B.E., Higgs D. 2003. Response of salt-stressed strawberry plants to supplementary calcium nitrate and/or potassium nitrate. Journal of Plant Nutrition 26: 543–560.

Marosz A. 2004. Effect of soil salinity on nutrient uptake, growth and decorative value of four ground cover shrubs. Journal of Plant Nutrition 27: 977–989.

Marosz A., Nowak J.S. 2008 . Effect of salinity stress on growth and macroelements uptake of four tree species. Dendrobiology 59: 23–29.

McBean E., Al-Nassri S. 1987. Migration pattern of deicing salts from roads. Journal of Environmental Management 25: 231–238.

Mousavi A., Lessani H., Babalar M., Talaei A.R., Fallahi E. 2008. Influence of salinity on chlorophyll, leaf water potential, total soluble sugars and mineral nutrients in two olive cultivars. Journal Plant Nutrition 31: 1906–1916.

Norrström A.C., Jacks G. 1998. Concentration and fractionation of heavy metals in roadside soils receiving de-icing salts. The Science of the Total Environment 218: 161–174.

Norrström A.C. Bergstedt E. 2001. The impact of road de-icing salts (NaCl) on colloid dispersion and base cation pools in roadside soils. Water Air and Soil Pollution 127: 281–299.

Qadir M., Oster J.D., Schubert S., Noble A.D., Sahrawat K.L. 2007. Phytoremediation of sodic and saline-sodic soils. Advances in Agronomy 96: 197–247. DOI 10.1016/S0065-2113(07)96006-X

Qadir M., and Schubert S. 2002. Degradation processes and nutrient constraints in sodic soils. Land Degradation and Development. 13: 275–294.

Sehmer L., Alaoui-Sosse B., Dizengremel P. 1995. Effect of salt stress on growth and detoxifying pathway of pendunculate oak. Journal of Plant Physiology. 147: 144–151.

Shainberg I., Letey J. 1984. Response of soils to sodic and saline conditions. Hilgardia, 52: 1–57.

Townsend A.M. 1980. Response of selected tree species to sodium chloride. Journal of American Societies Horticulture Science 105: 878–883.