INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/3/2016, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1521–1534
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2016.4.3.113

IMPACT OF SALTS FROM WINTER ROAD MAINTENANCE ON SELECTED PROPERTIES OF ROADSIDE SOILS

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Abstract

The impact of winter addition of salts to roadside soils was studied for the national road No. 28 in Poland, in Małopolska Region. The measured sections of the road No. 28 are two access ways to the city of Grybów. According to instructions of GDDiKA (General Directorate for National Roads and Motorways) both sampled routes: Grybów–Gorlice (sampling section G-G) and the section Nowy Sącz-Grybów (N-G) were included in II standard of winter road maintenance. The general increase in soil salinity, chloride concentration and pH values from the roadside soils was evidenced by the difference of results of two sampling campaigns, before and after winter season of 2015/16. Salinity indicators showed significant increase, even though weather winter season 2015/16 was rated as mild and road de-icing salts were applied at less-than-average rate. Soil hydraulic properties were calculated estimated from soil texture using pedo-transfer functions for estimating the dynamics of salts into soils, suggesting easy leaching of salts from topsoil.

Keywords: roadside soils, road salts, road de-icing,

INTRODUCTION

The aim of winter road maintenance is to improve safety on roads during winter seasons through prevention of ice formation on road surface, snow accumulation and re-freezing processes. Maintenance activities depends on standard class of the road and includes mainly: sanding, salting and snowplowing. In Poland, winter roads conservation for national routes is detailed regulated by guidelines of GDDiKA (General Directorate for National Roads and Motorways). To realize it, chemical substances approved to use by Regulation of Ministry of Environment in Official Journal of 2005 no. 230 item 1960 (Dz. U. z 2005 r. Nr 230 poz.1960 z późn. zm.) can be applied as de-icing materials. Them include liquid and solid forms of sodium chloride, calcium chloride, magnesium chloride and their mixture. Effectiveness of those substances were investigated (Czarna and Kołodziejczyk 2012), as well as their environmental impacts (Cekstere et al. 2010, Gałuszka et al. 2010, Kochanowska and Kusza 2010). Many country are switching from NaCl to $CaCl_2$ and $MgCl_2$ for avoiding the soil dispersion risk, although the cheapest treatment is NaCl, the most frequently used salt (Czarna 2013).

Roads salts winter application can negatively affect: soil quality, plants growth and health as well as surface – and ground-waters quality (Green et al. 2008). This environmental problem is present in research investigations (Mazur 2015, Mazur et al. 2011, Kochanowska and Kusza 2010) in cold climate countries since years. Researches are focused on salinity monitoring, describing the mechanisms of negative impact on environment, as well as modelling processes, trying to use models for prediction of road-salt dispersion in soil and water, or the environmental effects of de-icing (Amundsen et al. 2010, Lundmark and Jansson 2008).

The aim of this study was to examine and describe differences in salinity of roadside root-zone, before and after winter season, by comparing measurements of soil salinity indicators.

STUDY AREA DESCRIPTION

Sampling sites were located along the road No. 28. This 350 km National Road cross Małopolska and Podkarpackie regions. This road, of mountain character, has significant importance on the historical communication map of those regions, supporting heavy traffic. The sampling points are situated on Małopolska voivodship at the access roads to the city Grybów (coordinates of the city centre: latitude 49°37.4634′ N, longitude 20°56.8782′ E) (figure 1). The road connects the city and cross Nowy Sącz district is developed for ensuring the status of the sustainable development of the natural environment and its landscape protection (www.gminagrybow.pl).

Soil sampling points were located on the western and eastern side of the city (N-G and G-G respectively) (figure 2). Both sections are characterized by much higher traffic than other accesses to the Grybów city (voivodship road No. 981). The intensity of the traffic on those section was investigated by General

Directorate for National Roads and Motorways (GDDKiA 2015) and the average was 6834 vehicles per day for the measured road section.

Source: own work

Figure 1. Location of the studied area

Source: own work on the base of the map from www.google.pl

Figure 2. Location of the sampled road sections

The sampled road sections were included into the II standard of winter road maintenance. In this standard, roads snow and slippery on road surface and from hard parts of the roadsides need to be liquidate. Reducing slippery should not exceed more than 3-4 hours from the occurrence time (GDDKiA 2015).

The climate in this area has been classified as the Dfb in the Köppen-Geiger system. The average mean temperature is 6-8 °C and total annual precipitation ranges from 800 to 1000 mm. First frosts in this area occur at the beginning of October and lasts in mid-May. Number of days with snow cover is ranges from 90 to 100 (www.climate-data.org, www.gminagrybow.pl). The winter season 2015/16, in which sampling was performed, was 2º C warmer than the average winter (according to analyses of IMGW meteorological maps). Total annual precipitation during winter was normal as for this season (100 to 120 mm) (www.imgw.pl).

METHODOLOGY OF THE STUDY

Soil sampling

During the winter season of 2015, composite soil samples were collected from 60 sites at 0-30 cm depth (30 samples from N-G and 30 from G-G road segments). The sampling points were arranged in a subsection, where at the 50 m distance from each other samples were taken. This sampling scheme was repeated during the spring season of 2016 at the same sites. Literature review of roadside soils research suggested that, the greatest concentrations of Cl^- at the root zone of roadside soils are found from 1.5 meters to 3 meters of distance from the edge of the road, taking into account the ways of transport of de-icing salts. Dissolved salts can flow off the road or remain and be sprayed and splashed off the road by vehicles (www.michigan.gov). However, local conditions like weather, slope of road and roadside infrastructure can highly affect salt dispersion. According to other researchers in an study recommended sampling distance from edge of the road was 2 meters. Average altitude of sampling was 476 m above sea level, also sampling were done at the same sites in two campaigns according to dates of the start and the end of the road winter season (IMGW 2015).

Samples taken before winter season (in November 2015) are described as series AUTUMN and samples taken after winter season (in April 2016) are described as series SPRING.

Laboratory analyses of sampled soil properties

- Electrical Conductivity (method PN–EN 27888:1999) measured for 1:5 soil/water (weight/volume),

- pH determining (method PN–ISO 10390:1997) measured for 1:5 soil/water (weight/volume) as it is recommended by ISO standard and accepted by modern soil classifications (Kabała et al. 2016).
- On the base of EC measurements of AUTUMN samples, the 21 samples with the highest value of EC were analysed on chloride concentration by argentometric method (PN-ISO 9297).
- $CaCO_3$ determination measured by the classic Scheibler calcimeter method.
- Soil texture was analysed by Casagrande areometric method (PN-ISO 11277).
- Soil bulk density (BD) was determined by taking undisturbed samples in 100 cm^3 cylinders and weighting the dry soil sample.

Because water is the vector for soluble salts transport through the soil, and leaching of salts and especially Cl – ions, hydraulic properties were important in characterizing the soil studied, hydraulic properties were computed from soil texture data, according to Saxton pedotransfer functions (Saxton et al. 1986):

- saturated hydraulic conductivity (Hsat) estimates horizon permeabilty,
- field capacity (FC) defined as the level of soil moisture left in the soil after drainage of the gravitational water,
- wilting point (WP). The wilting point is defined as the soil moisture content at which most plants cannot exert enough force to remove water from small pores in the soil.
- plants available water content (AW). Water held between field capacity and the wilting point. (Scherer et al. 2013)

Data obtained from the different measurements, relating to the effect of using de-icing material, was analysed with PAST statistical package.

DISCUSION OF THE RESULTS

Mean values for the AUTUMN and SPRING sets of measurement in EC 1/5, $pH_{(H2O)}$ 1/5 and $CaCO_3$ content are expressed in table 1. In the measured area, there is a clear increase in soil EC (mean value from 144 $\mu S*cm^{-1}$ to 230 $\mu S*cm^{-1}$) and pH levels (mean value from 7.55 to 8.08) and slight change in carbonates values (from 7.49 to 7.82%) between the two sampling campaigns, November 2015 and April 2016.

The pH values change from neutral to slightly alkaline in both sampled section. The maximum values of pH in spring were found in points where measured EC was considerable increased also. Such slight alkaline soil solution reaction could be result of sodium chloride de-icing use, as it is described in literature

(Hulisz 2007), NaCl derivate reactions form small concentrations of Na_2CO_3 and $NaHCO_3$ in the soil solution.

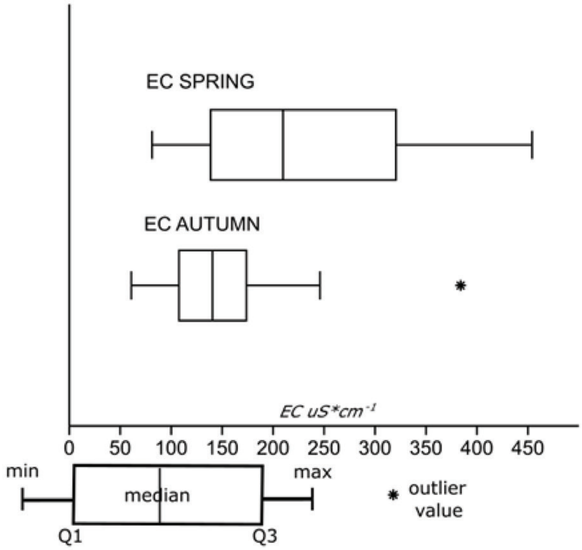
The highest 25 % of EC values were between 320.52 to 454.10 µS*cm^{-1} but still lower than level described in literature as salinity that can affect plant growth. For confirming statistically significant differences for EC between AUTUMN and SPRING measurements a t-Student test for dependent samples were use. For α = 0,05 the t value is – 5.455 and p-value is 2.73 *10^{-7}, test confirming statistically significant differences as shows graphically the figure 3.

Table.1 Basic statistics of roadside soil properties in AUTUMN and SPRING sets in both sampling section

Parameter	Minimum	Maximum.	Mean	25percentile	75percentile	Standard deviation	Coefficient of variation
EC AUTUMN µS*cm^{-1}	60.90	384.00	144.42	107.62	173.80	53.37	36.95
EC SPRING µS*cm^{-1}	81.20	454,10	230.58	138.695	320.52	107.28	46.52
$pH_{(H2O)}$ AUTUMN	6.72	8.55	7.55	7.32	7.78	0.35	4.68
$pH_{(H2O)}$SPRING	7.5	9.02	8.08	7.76	8.35	0.40	4.96
$CaCO_3$ AUTUMN %	0	7.49	1.42	0	2.29	2.18	152.89
$CaCO_3$SPRING %	0	7.82	1.35	0	1.91	2.12	155.89

Soil texture was measured by Cassagrande'a method and described using USDA classification. The 86 % of soil samples correspond to soils with textute sandy-loam (65% of the cases) and loam (21% of the cases). Loamy sands texture was found only in 5 sampling points and silty loam texture in 3 cases. In the sample section N-G (Nowy Sącz – Grybów) texture of roadside soils was "coarser" than in section G-G (figure 4).

Bulk density BD (mean value 1.67 g*cm^{-3}) measured in core samples (cilinder method) shows that compaction is present in sampled soils, and the 1.61 is value under of which 75% of the observations may be found. This soil compaction increase noticed here, by lightly raised bulk density values, could negatively affect soil-water characteristics as reduced available water content and infiltration.

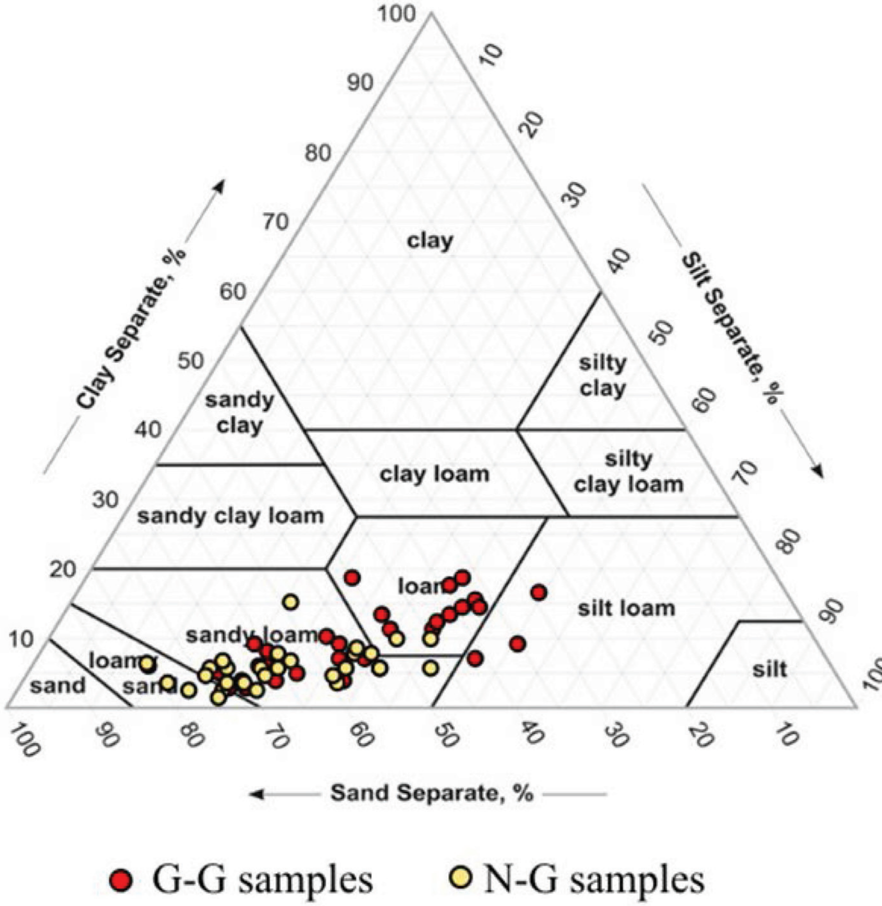


Source: own work

Figure 3. Distribution of EC values in the soil samples from SPRING and AUTUMN sets

Table 2. Basic statistics of the hydraulic soil parameters for both sampled section

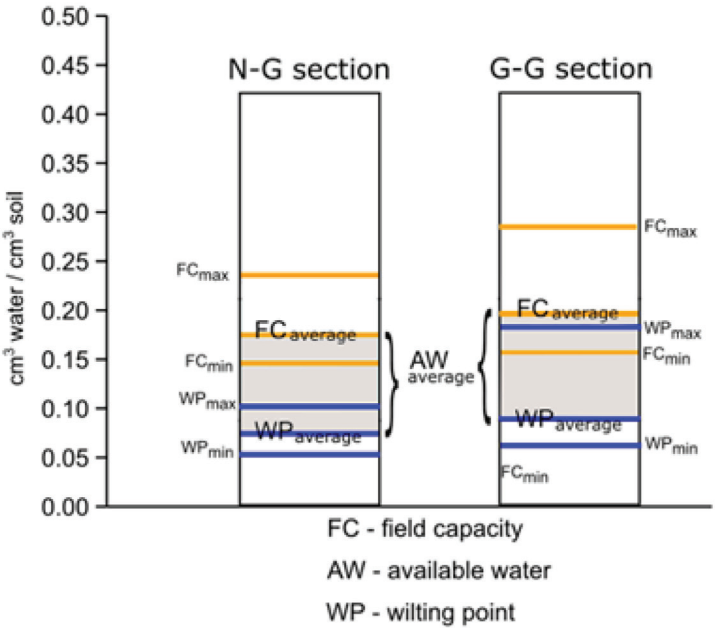
Parameter	Minimum	Maximum	Mean	25percentile	75percentile	Standard dev.	Coefficient of variation
Wilting Point WP (cm^3 water per cm^3 soil)	0.052	0.119	0.081	0.069	0.092	0.016	20.845
Field Capacity FC (cm^3 water per cm^3 soil)	0.147	0.271	0.201	0.169	0.229	0.033	16.519
Available Water AW (cm^3 water per cm^3 soil)	0.086	0.164	0.121	0.105	0.135	0.019	15.774
Saturated Hydraulic Conductivity Hsat ($cm*h^{-1}$)	0.979	8.127	4.195	2.651	5.416	1.880	44.782



Source: own work on base of textural triangle from http://www.nrcs.usda.gov

Figure 4. Soil texture

Because sodium and chloride ions are the easiest leached ions in soil by rain water, knowing the water characteristic of studied soils is important. This study developed Saxton texture based method to determine soil moisture characteristic. Values for full set of measurements are: wilting point WP (0.081 cm^3 water per cm^3 soil) and field capacity FC (0.20 cm^3 water per cm^3 soil). Border values of crop field soil were use for interpreting those parameters: WP average between 0,061-0,090 is interpreted as low and average FC located between 0.171-0.230 as small (Paluszek 2011). Available water content AW average value is 0.121 cm^3 water per cm^3 soil (figure 5). Saturated Hydraulic Conductivity (Hsat) ranges between 0.979 to 8.127 $cm*h^{-1}$, with high dispersion of values (table 2). The permeability category based on the (Hsat) and NRCS classification showed that the soils Saturated Hydraulic Conductivity in 60 % samples were described as high and in 40% as moderately high.



Source: own work

Figure 5. Water holding capacity characteristic

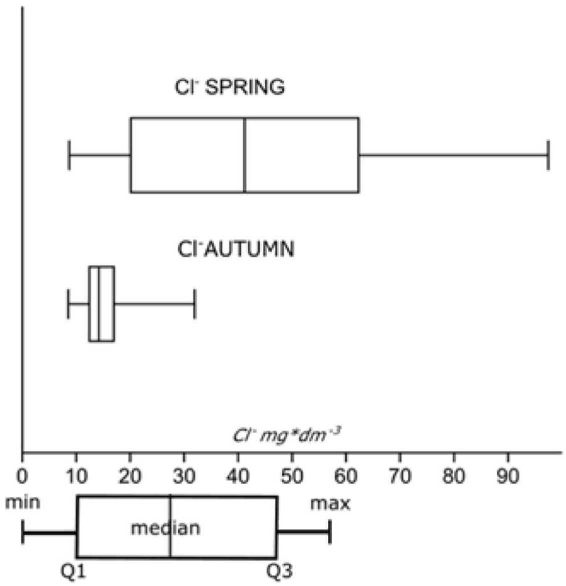
Chlorides are easily leached out to the deeper layers of the soil and could reach groundwater level. Movement of Cl– is even faster than water molecules because of the negative charging of soil particle influence (Smith 1972). Increase in Cl– concentration in top level of soil gives negative effect, at short term. To evidence it in monitoring research, sampling should be collected just after winter salt road maintenance season.

Chloride concentration analysed values in this research ranged from 8.52 to 97.45 mg*dm^{-3} (figure 6), with mean value 15.21 mg*dm^{-3} for set AUTUMN and 43.80 mg*dm^{-3} for soil samples SPRING (table 3). In Autumn 25 % of observations were higher than 20.11 mg*dm^{-3} in SPRING samples this value increase to 62.30 mg*dm^{-3} (table 3).

Average values of chloride concentration in both sets differ greatly from each other (table 3). For confirming statistically significant differences between sets AUTUMN and SPRING, was used a Wilcoxon rang test for dependent samples. For $\alpha = 0{,}05$ the W value is 220 and p-value is 0.00021393, test confirming statistically significant differences for chloride concentration between the two sets. It confirmed strongly the effect of winter road salting on increasing of Cl– in soil solution.

Table 3. Basic statistics of the Cl– concentration in AUTUMN and SPRING 1/5 soil/water extracts w/v.

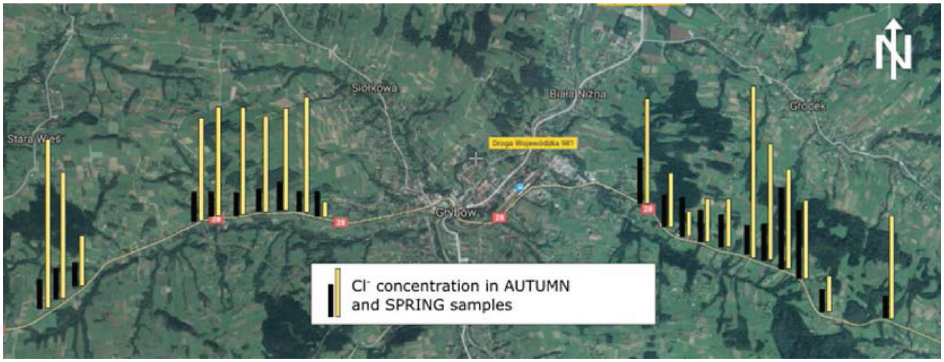
Parameter	Minimum	Maximum	Mean	25percentile	75percentile	Standard deviation	Coefficient of variation
Cl^-AUTUMN $mg*dm^{-3}$	8.52	31.95	15.21	12.43	20.11	5.40	35.49
Cl– SPRING $mg*dm^{-3}$	8.57	97.45	43.80	16.95	62.30	24.22	55.25



Source: own work

Figure 6. Distribution of Cl– values in the soil samples from SPRING and AUTUMN sets

Results from sections N-G and G-G were also compared in order to determine differences in Cl– content in roadside soils in different sections of the road No. 28.



Source: own work on the base of the map from www.google.pl

Figure 7. Chloride concentrations in study area – in AUTUMN and SPRING measurements sets.

A strong correlation was observed in both series between Cl – and EC measurements (Pearson R 0.90 for SPRING series and 0.88 for AUTUMN series). Both EC and Cl – measurements shows higher values at SPRING series (figure 7 and 8).

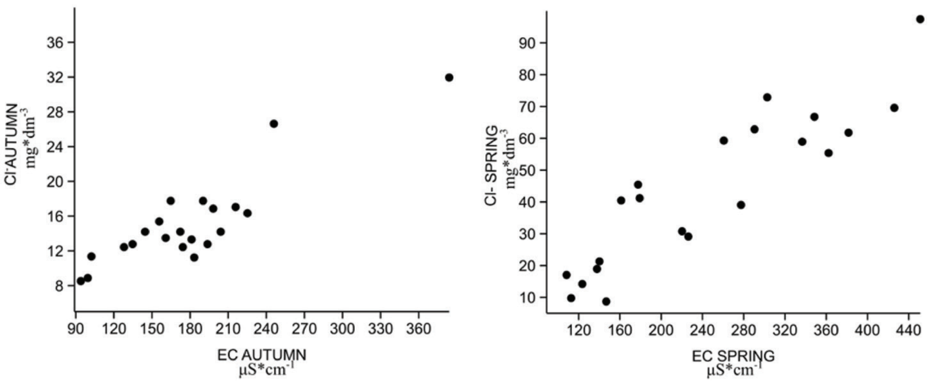


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Figure 8. Graphical results of the correlation Cl – /EC

CONCLUSIONS

The salinity caused by road de-icing material affects green belts adjoining to road. Although it is surface limited, every year road additions of salts projects a net increase of salinity and extension. Results of using salts became more visible (especially in cities). To assess problem, it's scale and character is important to monitor the changes. This studies on roadside soils along National Road No. 28 was treated as an example of soils exposed to an influence of NaCl (coming from de-icing salts).

This study showed that after winter values of electrical conductivity in soil 1:5 extracts are significantly higher in SPRING set than in AUTUMN probes. Average EC before winter maintenance road season was 144.42 $\mu S*cm^{-1}$. In SPRING sampling average value was two-fold. Soils pH increase after winter season and soils indicate to be slightly more alkaline (rarely with pH > 9).

The studied soils present a permeability (based on saturated hydraulic conductivity values) in 60 % of samples as a high, and in 40 % as moderate.

Exists significant differences in chloride concentration on roadside soils along National Route 28 (in measured section) between samples collected in AUTUMN and SPRING sets. Average Cl– concentration before winter season was 15.21 $mg*dm^{-3}$. In second spring sampling campaign average value was three-fold this concentration. Chloride residual concentration after winter season from the section N-G was much higher than from G-G section. This difference could be explained by the distance between the edge of the road and soil sampling points in G-G samples and N-G.

Strong correlation was noticed in both measuring series between Cl– and EC measured values – Pearson R 0.90 for SPRING series and 0.88 for AUTUMN series.

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Received: 21.10.2016
Accepted: 03.11.2016