engineering proceedings

MDPI

Proceeding Paper

Evaluation of the Effect of De-icing Materials on Soil Quality in Selected Areas of the Moravian-Silesian Region †

Lucie Syrová *, Bohdana Šimáčková, Lukáš Balcařík and Samaneh Shaghaghi

Department of Environmental Engineering, Faculty of Mining and Geology, VŠB–Technical University of Ostrava, 17. Listopadu 2172/15, Poruba, 708 00 Ostrava, Czech Republic; bohdana.simackova.st@vsb.cz (B.Š.); lukas.balcarik.st@vsb.cz (L.B.); shaghaghisamaneh@gmail.com (S.S.)

* Correspondence: lucie.syrova.st@vsb.cz

† Presented at the 4th International Conference on Advances in Environmental Engineering, Ostrava, Czech Republic, 20–22 November 2023.

Abstract: This study focuses on the evaluation of the influence of sodium chloride on soil quality in selected locations in the Moravian-Silesian Region. A pilot study was performed in which soil samples were collected at distances of 5 m, 10 m and 20 m perpendicular to the road. The soil samples were analyzed in laboratories to demonstrate the occurrence and possible influence of de-icing material on soil and environmental quality in the vicinity of roads.

Keywords: soils; de-icing; NaCl; sodium chloride

check for updates

Citation: Syrová, L.; Šimáčková, B.; Balcařík, L.; Shaghaghi, S. Evaluation of the Effect of De-icing Materials on Soil Quality in Selected Areas of the Moravian-Silesian Region. *Eng. Proc.* **2023**, *57*, 26. https://doi.org/10.3390/engproc2023057026

Academic Editors: Adriana Estokova, Natalia Junakova, Tomas Dvorsky, Vojtech Vaclavik and Magdalena Balintova

Published: 5 December 2023

1. Introduction

Inert gritting material (gravel) or chemically active material is used to make roads more passable. By far the most commonly used chemically active material for winter road maintenance is sodium chloride (NaCl). In addition to its positive impacts, the use of de-icing salts can have unintended environmental consequences. In addition to retaining Na^+ and Cl^-, road maintenance with NaCl can also affect the chemical and physical properties of the soil [1]. Sodium chloride causes an increase in pH or release of ammoniacal N [2]. Ion exchange processes can lead to replacement and subsequent leaching of base cations and plant nutrients such as Ca^{2+}, Mg^{2+} and K^+ if excessive amounts of Na^+ enter the system [1]. The accumulation of NaCl in soil can also lead to impaired water permeability, poor aeration, surface crusting and increased alkalinity [3]. Bäckström et al. [4] stated in their study that pH in soil solutions decreased by one unit due to ion exchange. In their study, Baraza and Hasenmueller [1] found that soils temporarily store salts, either in pore-water or adsorbed on soil particles. Chloride ions in soils increase osmotic pressure, which affects the ability of the soil to retain water. They also affect soil organisms, reducing overall soil productivity [5]. Among microorganisms, salinization has been shown to weaken the competitiveness of surviving populations. In their study, Ke et al. [6] observed that the higher the salt content applied, the greater the similarity in fungal and bacterial populations. The similarity of fungi increased from 32% to 75% and the similarity of bacteria from 35% to 83%. Chloride and sodium ions also cause the release and transport of metals such as Pb and Pd into the soil [7]. Bäckström et al. [4] in a study of mobilization of heavy metals by de-icing salts in a roadside environment found that the heavy metal content in soil increased during winter season. The concentration of Cd in the aqueous phase increased in response to the ion exchange process. Zn concentration increased due to ion exchange with calcium. Amrhein et al. [8], in their study on the effect of de-icing salts on metal and organic matter mobilization in roadside soils, showed that NaCl released metals (Cr, Pb, Ni, Fe and Cu) bound to organic matter and colloids. They also found that the release is most significant at high adsorbed sodium content and low ionic strength.

If sodium ions are present in the soil in optimal concentrations, they have a positive effect on the soil and plants. Sodium ions help to maintain moisture in the soil and help plants to survive in low moisture areas [9]. However, most plants cannot tolerate higher levels of soluble salts in water [10]. Salt ions cause osmotic and ionic stress to plants. Soil salinization interferes with water and nutrient uptake by roots [11]. It also affects plant morphology and anatomy, such as reduction in root growth and leaf development. High concentrations of Na^+ in soils can reduce the availability of other nutrients to plants and can lead to reduced plant growth [10]. In woody plants, sodium uptake is usually more effectively regulated than chloride uptake. The concentrations of these ions are also higher in older leaves than in young leaves [12]. Plants detect Na^+ through specific mechanisms (root halotropism). The mechanisms are activated when they detect salt exposure, which triggers the Salt Overly Sensitive (SOS) pathway [13].

However, some plant species, especially halophytes, benefit from higher concentrations of sodium and chloride ions. Halophytes live their life cycle in extremely saline conditions, which has led them to develop adaptive responses to stress conditions in order to survive. Adaptive conditions in salt-tolerant plants have evolved as the ability to tolerate stress by establishing different mechanisms. Successful adaptation to salt tolerance in halophytes occurs through the synthesis of a wide range of antioxidants (secondary metabolites) [9]. Plants also use tissue tolerance, sodium exclusion, tolerance to osmotic stress, and tissue-specific sodium sequestration, with many transport genes involved in Na^+ partitioning processes in plants [13].

The aim of the pilot study was to evaluate the effect of chemically active de-icing material (NaCl) on soils in Bruntál, Nebory and Ropice with a comparison to soil that does not undergo winter maintenance in Bystřice.

2. Methods and Materials

2.1. Sample Collection and Preparation

Soil samples were collected within the Moravian-Silesian Region, Czech Republic, specifically in Bruntál—III/0451 (49°58′34″ N 17°27′08″ E), Nebory—II/474 (49°40′34.4″ N 18°37′05.5″ E), Ropice—I/11 (49°42′52.4″ N 18°37′05.8″ E) and Bystřice—III/01143 (49°37′56.9″ N 18°43′32.9″ E) at distances of 5 m, 10 m and 20 m perpendicular to the road. Samples were collected monthly from December 2021 at three sites that were maintained with NaCl (Bruntál, Nebory and Ropice) and one site without NaCl maintenance (Bystřice). Given the objective to demonstrate the presence of chlorides in soils, rather than its distribution at depth, disturbed soil samples were collected. Approximately 1 kg of material was collected from each sampling site, depending on soil fraction and moisture content. The samples were then dried, homogenized and sieved through a 2 mm diameter analytical stainless steel sieve Preciselekt, s.r.o. (Malhostovice, Czech Republic).

2.2. Methods of Determined Parameters

Exchangeable acidity (pH/$CaCl_2$) was determined according to ČSN EN ISO 10390 (836221) Soil, treated biowaste and sludge—Determination of pH [14]. The principle of the method is the determination of pH in a calcium chloride solution with a concentration of 0.01 mol L^{-1} (pH/$CaCl_2$). The solid-to-liquid ratio is 1:5 (volume fraction). The standard allows a range of extraction duration from 2 h to 24 h. The values were measured using a laboratory pH meter inoLab® pH 7110 by Xylem Analytics Germany Sales GmbH (Weilheim, Germany). The results were interpreted according to Table 1.

The dissolved salt content was determined on the basis of electrical conductivity according to standard ČSN EN 27888 (757344) Water quality—determination of electrical conductivity (ISO 7888:1985) [16]. The principle of the method is to measure the conductivity in a filtrate prepared from a 1:5 soil/distilled water leachate, which has been shaken for 5 min in the incubator shaker KS 4000i Control, IKA® (Staufen, Germany). The values were measured with the laboratory conductivity meter inoLab® Cond 7110 by Xylem Analytics

Germany Sales GmbH (Weilheim, Germany). The results were interpreted according to Table 2.

Table 1. Soil classification based on exchangeable acidity—pH/$CaCl_2$ [15].

pH/$CaCl_2$	Soil Evaluation	pH/$CaCl_2$	Soil Evaluation	pH/$CaCl_2$	Soil Evaluation
<3	Extremely acidic	6.0–6.9	Slightly acidic	9.1–10.0	Strongly alkaline
3.0–3.9	Very strongly acidic	7.0	Neutral	10.1–11.0	Very strongly alkaline
4.0–4.9	Strongly acidic	7.1–8.0	Slightly alkaline	>11.0	Extremely alkaline
5.0–5.9	Moderately acidic	8.1–9.0	Moderately alkaline		

Table 2. FAO (USDA) classification for soil salinity assessment [17].

Conductivity (mS·cm^{-1})	Salinity	Conductivity (mS·cm^{-1})	Salinity
<0.75	None	4.0–8.0	Strong
0.75–2.0	Slight	8.0–15.0	Very strong
2.0–4.0	Moderate	>15	Extreme

Soil leachate was prepared with distilled water in the ratio of 1:10 for chloride determination. The soil leachate was shaken for 24 h on the incubator shaker KS 4000i Control, IKA® (Germany) and then filtered through a PRAGOPOR 6 membrane filter with a pore size of 0.4 µm (PRAGOCHEMA, Prague, Czech Republic). Chlorides were determined in the filtrate by titration with silver nitrate volumetric solution in neutral medium to potassium chromate indicator according to norm ISO 9297 (757420) Water quality. Determination of chloride. Silver nitrate titration with chromate indicator (Mohr's method) [18]. The principle of the method is titration of the sample with a volumetric solution of silver nitrate ($AgNO_3$) to form a precipitate of silver chloride (Ag_2CrO_4). Potassium chromate (K_2CrO_4) is used as an indicator to visually indicate the equivalence point.

3. Results and Discussion

An important physico-chemical property of soils is the soil reaction (pH)—the soil acidity. It consists of two parts: active acidity and exchangeable (passive) acidity. This is the type of acidity in which the concentration of free H^+ in the soil solution varies only slightly compared to exchangeable acidity. Exchangeable acidity is a measurement of H^+ and Al^{3+} ions retained or fixed on the soil colloid [19]. The observed values including their evaluation are presented in Table 3.

The soils located near the roads in Nebory and Ropice, which are maintained chemically with NaCl in winter, can be classified as slightly acidic based on the average pH/$CaCl_2$ value and moderately acidic in Bruntál. The soil near the road in Bystřice, which does not undergo chemically active winter maintenance, can be classified as slightly acidic. Based on the measured pH values (Table 3), it can be concluded that the pH values of the soils in Nebory, Ropice, Bruntál and Bystřice do not show a seasonal dependence. Distance from the road also has no effect on soil pH. Equiza et al. [3] in their study reported that soil pH values at roadside sites were significantly higher than at control sites, ranging from pH 7.6 to 8.5 due to the use of de-icing salts. Bäckström et al. [4] in their study reported that the pH of the soil solutions decreased by one unit due to ion exchange as a result of the application of de-icing material (NaCl) during the winter season. However, neither of these trends were observed in this pilot study. Soil pH did not change significantly as a result of chemically active road treatment. The soil conductivity value is used to determine soil salinity, which is proportional to the amount of dissolved salts present in the soil. It is usually higher in soils with a higher content of mineral salts such as calcium, magnesium and sodium. It can be affected by various factors such as soil texture, organic matter content, pH value and water content. The values observed, including their evaluation, are presented in Table 4.

Table 3. pH/$CaCl_2$ of conducted soil samples from December 2021 to March 2023.

	Nebory			Ropice			Bruntál			Bystřice		
DATE	**5 m**	**10 m**	**20 m**	**5 m**	**10 m**	**20 m**	**5 m**	**10 m**	**20 m**	**5 m**	**10 m**	**20 m**
XII/21	6.90	6.58	6.64	7.05	7.01	6.97	6.40	6.20	6.10	6.25	6.31	6.27
I/22	6.81	6.56	6.61	7.08	7.03	6.99	5.70	5.50	5.60	6.20	6.16	6.19
II/22	6.82	6.54	6.59	6.94	6.87	6.85	5.70	5.60	5.50	6.38	6.44	6.34
III/22	6.73	6.49	6.53	6.89	6.83	6.79	5.80	5.60	5.60	6.30	6.39	6.30
IV/22	6.69	6.48	6.52	6.81	6.77	6.72	5.80	5.70	5.60	6.21	6.12	6.19
V/22	6.64	6.51	6.44	6.79	6.73	6.71	5.70	5.50	5.50	6.27	6.20	6.23
VI/22	6.63	6.42	6.49	6.83	6.86	6.74	5.70	5.60	5.50	6.33	6.24	6.17
VII/22	6.68	6.49	6.43	6.80	6.78	6.77	5.70	5.60	5.50	6.22	6.25	6.18
VIII/22	6.64	6.57	6.51	6.90	6.85	6.84	5.80	5.60	5.60	6.37	6.32	6.29
IX/22	6.72	6.54	6.59	6.87	6.83	6.82	5.80	5.70	5.70	6.13	6.20	6.16
X/22	6.69	6.57	6.58	6.81	6.89	6.86	5.80	5.70	5.60	6.21	6.36	6.27
XI/22	6.81	6.62	6.48	7.00	6.93	6.91	6.00	5.60	5.80	6.28	6.19	6.23
XII/22	6.80	6.50	6.64	7.00	7.02	6.95	6.30	5.90	6.10	6.15	6.26	6.20
I/23	6.74	6.48	6.47	7.09	6.95	7.00	6.20	6.00	5.90	6.24	6.20	6.30
II/23	6.85	6.73	6.56	6.95	6.84	6.85	5.80	5.60	5.50	6.40	6.50	6.30
III/23	6.93	6.50	6.67	6.84	6.85	6.66	5.70	5.50	5.60	6.34	6.38	6.35
IV/23	6.60	6.42	6.40	6.76	6.70	6.68	5.80	5.70	5.50	6.20	6.25	6.18
AVERAGE	6.75	6.53	6.54	6.91	6.87	6.83	5.86	5.68	5.66	6.26	6.28	6.24
MAX	6.93	6.73	6.67	7.09	7.03	7.00	6.40	6.20	6.10	6.40	6.50	6.35
MIN	6.60	6.42	6.40	6.91	6.87	6.83	5.70	5.50	5.50	6.13	6.12	6.16

Table 4. Conductivity of conducted soil samples from December 2021 to March 2023 in mS·cm^{-1}.

	Nebory			Ropice			Bruntál			Bystřice		
DATE	**5 m**	**10 m**	**20 m**	**5 m**	**10 m**	**20 m**	**5 m**	**10 m**	**20 m**	**5 m**	**10 m**	**20 m**
XII/21	0.23	0.17	0.21	0.21	0.18	0.15	0.11	0.09	0.07	0.11	0.11	0.13
I/22	0.20	0.15	0.19	0.18	0.17	0.13	0.10	0.07	0.06	0.17	0.16	0.14
II/22	0.19	0.18	0.13	0.13	0.11	0.10	0.06	0.05	0.05	0.17	0.12	0.13
III/22	0.16	0.18	0.14	0.14	0.16	0.12	0.06	0.04	0.04	0.18	0.15	0.14
IV/22	0.20	0.14	0.17	0.15	0.18	0.15	0.06	0.04	0.04	0.18	0.14	0.10
V/22	0.18	0.13	0.15	0.13	0.17	0.15	0.06	0.05	0.04	0.12	0.11	0.13
VI/22	0.16	0.16	0.13	0.16	0.14	0.10	0.05	0.05	0.04	0.12	0.12	0.15
VII/22	0.14	0.15	0.13	0.18	0.15	0.11	0.04	0.04	0.04	0.14	0.13	0.14
VIII/22	0.19	0.17	0.13	0.12	0.12	0.15	0.04	0.04	0.04	0.12	0.12	0.13
IX/22	0.21	0.23	0.18	0.16	0.17	0.13	0.04	0.05	0.04	0.16	0.14	0.15
X/22	0.19	0.13	0.15	0.19	0.14	0.11	0.06	0.04	0.04	0.11	0.13	0.12
XI/22	0.21	0.14	0.17	0.21	0.16	0.14	0.05	0.05	0.04	0.14	0.13	0.12
XII/22	0.22	0.16	0.20	0.20	0.17	0.12	0.13	0.10	0.10	0.10	0.10	0.11
I/23	0.19	0.13	0.17	0.18	0.11	0.11	0.10	0.08	0.07	0.18	0.18	0.12
II/23	0.18	0.14	0.13	0.09	0.18	0.11	0.07	0.06	0.05	0.17	0.14	0.19
III/23	0.18	0.12	0.13	0.12	0.15	0.1	0.06	0.04	0.04	0.12	0.12	0.12
IV/23	0.25	0.15	0.2	0.2	0.14	0.11	0.06	0.04	0.04	0.14	0.13	0.17
AVERAGE	0.19	0.15	0.16	0.16	0.15	0.12	0.07	0.06	0.05	0.14	0.13	0.13
MAX	0.25	0.23	0.21	0.21	0.18	0.15	0.13	0.10	0.10	0.18	0.18	0.19
MIN	0.14	0.12	0.13	0.09	0.11	0.10	0.04	0.04	0.04	0.10	0.10	0.10

The soils located near the road in Nebory, Ropice and Bruntál, which are maintained by chemically active material NaCl in winter, are classified as non-saline based on the average conductivity value. The soil near the road in Bystřice, which is not maintained by chemically active material, can be classified as non-saline. Based on the measured values, it can be concluded that the conductivity of the soils in Nebory, Ropice, Bruntál and Bystřice does not show a seasonal dependence. In their study, Bäckström et al. [4] reported that the conductivity values increased significantly due to chemically active road maintenance, and with increasing distance from the road, the conductivity values decreased according to the measurements, with an impact distance of approximately 10 m. However, this pilot study failed to demonstrate the effect of chemically active winter maintenance on the measured conductivity values (Table 4) in soils in the selected locations. The impact of distance was also not demonstrated, i.e., distance from the road also has no effect on soil conductivity.

In addition to pH and conductivity, chloride ions were also determined in soil samples. Chloride ions were determined below the detection limit at all sites.

The effect of de-icing materials on soil quality depends on many factors. Among the most important factors are the amount and type of de-icing material used, the duration of application of the chemically active material, the frequency of application, the type of soil in the vicinity and, particularly, the current weather. Sodium chloride helps to keep roads passable, ensuring traffic safety during the winter months. The results so far indicate that the advantages of the chemically active material, sodium chloride, outweigh the disadvantages in selected locations in the Moravian-Silesian Region. In all three locations (Nebory, Ropice and Bruntál), where there is regular chemical winter road maintenance, sodium chloride is used as a de-icing material. The pilot study should be complemented by other investigation at sites that could help to complete the overall overview of the potential impact of sodium chloride on roads in the Moravian-Silesian Region.

4. Conclusions

This pilot study evaluated the effect of de-icing materials on soil quality in selected locations in the Moravian-Silesian Region.

Author Contributions: Conceptualization, L.S.; methodology, B.Š., L.S., S.S. and L.B.; software, S.S.; validation, L.S. and L.B.; formal analysis, B.Š.; investigation, L.S.; resources, B.Š.; data curation, L.S. and B.Š.; writing—original draft preparation, L.S., B.Š., S.S. and L.B.; writing—review and editing, L.S., S.S., B.Š. and L.B.; visualization, S.S.; supervision, L.S.; project administration, S.S.; funding acquisition, L.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Baraza, T.; Hasenmueller, E.A. Road salt retention and transport through vadose zone soils to shallow groundwater. *Sci. Total Environ.* **2021**, *755*, 142240. [CrossRef] [PubMed]
2. Lancaster, N.A.; Bushey, J.T.; Tobias, C.R.; Song, B.; Vadas, T.M. Impact of chloride on denitrification potential in roadside wetlands. *Environ. Pollut.* **2016**, *212*, 216–223. [CrossRef] [PubMed]
3. Equiza, M.A.; Calvo-Polanco, M.; Cirelli, D.; Señorans, J.; Wartenbe, M.; Saunders, C.; Zwiazek, J.J. Long-term impact of road salt (NaCl) on soil and urban trees in Edmonton, Canada. *Urban For. Urban Green.* **2017**, *21*, 16–28. [CrossRef]
4. Bäckström, M.; Karlsson, S.; Bäckman, L.; Folkeson, L.; Lind, B. Mobilisation of heavy metals by deicing salts in a roadside environment. *Water Res.* **2004**, *38*, 720–732. [CrossRef] [PubMed]
5. Rietz, D.N.; Haynes, R.J. Effects of irrigation-induced salinity and sodicity on soil microbial activity. *Soil Biol. Biochem.* **2003**, *35*, 845–854. [CrossRef]
6. Ke, C.; Li, Z.; Liang, Y.; Tao, W.; Du, M. Impacts of chloride de-icing salt on bulk soils, fungi, and bacterial populations surrounding the plant rhizosphere. *Appl. Soil Ecol.* **2013**, *72*, 69–78. [CrossRef]
7. Pahlavan, F.; Ghasemi, H.; Yazdani, H.; Fini, E.H. Soil amended with Algal Biochar Reduces Mobility of deicing salt contaminants in the environment: An atomistic insight. *Chemosphere* **2023**, *323*, 138172. [CrossRef] [PubMed]

8. Amrhein, C.; Strong, J.E.; Mosher, P.A. Effect of deicing salts on metal and organic matter mobilization in roadside soils. *Environ. Sci. Technol.* **1992**, *26*, 703–709. [CrossRef]
9. Khandare, S.D.; Singh, A.; Chaudhary, D.R. Halophytes: A potential source of antioxidants. In *Marine Antioxidants*; Elsevier: Amsterdam, The Netherlands, 2023; pp. 185–196. [CrossRef]
10. Parida, A.K.; Das, A.B. Salt tolerance and salinity effects on plants: A review. *Ecotoxicol. Environ. Saf.* **2005**, *60*, 324–349. [CrossRef] [PubMed]
11. Munck, I.A.; Bennett, C.M.; Camilli, K.S.; Nowak, R.S. Long-term impact of de-icing salts on tree health in the Lake Tahoe Basin: Environmental influences and interactions with insects and diseases. *For. Ecol. Manag.* **2010**, *260*, 1218–1229. [CrossRef]
12. Hanslin, H.M. Short-term effects of alternative de-icing chemicals on tree sapling performance. *Urban For. Urban Green.* **2011**, *10*, 53–59. [CrossRef]
13. Venkataraman, G.; Shabala, S.; Véry, A.A.; Hariharan, G.N.; Somasundaram, S.; Pulipati, S.; Sellamuthu, G.; Harikrishnan, M.; Kumari, K.; Shabala, L.; et al. To exclude or to accumulate? Revealing the role of the sodium HKT1;5 transporter in plant adaptive responses to varying soil salinity. *Plant Physiol. Biochem.* **2021**, *169*, 333–342. [CrossRef] [PubMed]
14. *ČSN EN ISO 10390 (836221)*; Soil, Treated Biowaste and Sludge—Determination of pH. Czech Standardization Agency: Prague, Czech Republic, 2022.
15. Schachtschabel, P.; Scheffer, F. *Lehrbuch der Bodenkunde: Unter Mitarb. von W. R. Fischer*; Ferdinand Enke Verlag: Stuttgart, Germany, 1992; ISBN 3432847734.
16. *ČSN EN 27888 (757344)*; Water Quality. Determination of Electrical Conductivity (ISO 7888:1985). Czech Standards Institute: Prague, Czech Republic, 1996.
17. Food and Agriculture Organization of the United Nations. *Mapping of Salt-Affected Soils: Technical Manual*; FAO: Rome, Italy, 2020; ISBN 978-92-5-132687-9. Available online: https://www.fao.org/3/ca9215en/ca9215en.pdf (accessed on 22 June 2023).
18. *ČSN ISO 9297 (757420)*; Water Quality. Determination of Chloride. Silver Nitrate Titration with Chromate Indicator (Mohr's Method). 02/1996. Czech Standards Institute: Prague, Czech Republic, 1996.
19. Onwuka, M.I.; Ozurumba, U.V.; Nkwocha, O.S. Changes in Soil pH and Exchangeable Acidity of Selected Parent Materials as Influenced by Amendments in South East of Nigeria. *J. Geosci. Environ. Prot.* **2016**, *4*, 80–88. [CrossRef]