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Abstract

Roadside vegetation provides a multitude of ecosystem services, including pollutant remediation, runoff reduction, wildlife habitat, and aesthetic scenery. Establishment of permanent vegetation along paved roads after construction can be challenging, particularly within 1 m of the pavement. Adverse soil conditions could be one of the leading factors limiting roadside vegetation growth. In this study, we assessed soil physical and chemical properties along a transect perpendicular to the road at six microtopographic positions (road edge, shoulder, side slope, ditch, backslope, and field edge) along two highway segments near Beaver Crossing and

Sargent, NE. At the Beaver Crossing site, Na concentration was 81 times, exchangeable Na 66 times, and cone index (compaction parameter) six times higher at the road-edge position (closest to the paved road and with sparse vegetation) compared to positions with abundant vegetation (ditch or field edge). At the Sargent site, Na concentration was 111 times, exchangeable Na 213 times, and cone index up to two times higher at the road-edge position compared with ditch or field-edge positions. Likewise, electrical conductivity was higher and macroaggregation and water infiltration were lower at the road edge than at the ditch or field-edge positions. Soil properties improved with increasing distance from the road. Exchangeable Na percentage and cone index at the road-edge position exceeded threshold levels for the growth of sensitive plants. Thus, high Na concentration and increased compaction at the road edge appear to be the leading soil properties limiting vegetation establishment along Nebraska highways.

Abbreviations: EC, electrical conductivity; CEC, cation exchange capacity; NDOT, Nebraska Department of Transportation.

Core Ideas

- Roadside soil properties varied with microtopographic position along a transect perpendicular to paved road.
- The road edge had highest compaction, Na, electrical conductivity, and pH.
- The road edge had the lowest water infiltration and macroaggregation.
- Roadside compaction, Na, and electrical conductivity exceeded threshold levels for plants.

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1 Introduction

Establishing permanent vegetation along roadsides is essential to maintain or enhance ecosystem services. Well-established vegetation can provide many regulating, provisioning, cultural, and recreational ecosystem services. Specifically, it can stabilize slopes, control erosion, reduce water and air pollution, and improve natural aesthetic appeal, habitat for wildlife, and others (Akbar, Hale, & Headley, 2003; Barrett, Lantin, & Austrheim-Smith, 2004; Kasten, Stenolen, Caldwell, & Oberhauser, 2016; McCleery, Holdorf, Hubbard, & Peer, 2015; Ozdemir, 2019). For example, vegetative cover along roadsides can reduce total suspended solids by 77–97% and Cu, Pb, and Zn by 76–98% at vegetation widths of 4.2–13 m (Barrett et al., 2004). Roadsides

can also provide important refuge for insects, birds, and small mammals, particularly in areas dominated by agriculture (McCleery et al., 2015; Daniels et al., 2018; Kasten et al., 2016). In open landscapes like the U.S. Great Plains, snowdrifts can be a major problem. However, the standing residue from roadside vegetation traps snowfall, reducing labor to clear the snowdrifts. Roadsides with little or no surface cover are often eroded and have reduced ecosystem service potential.

Establishment of vegetation postconstruction is often difficult, especially within 1 m of the pavement. For example, in Nebraska, despite repeated seeding efforts by the Nebraska Department of Transportation (NDOT), vegetation does not establish well on some roadsides (NDOT, personal communication, 2014). Some of the factors limiting vegetation establishment could include adverse soil properties, hot and dry microclimates, vehicle traffic emissions, road maintenance activities, and the use of deicing salts (Forman et al., 2003; Neher, Asmussen, & Lovell, 2013). Roadside soils are highly disturbed and generally compacted as a result of mixing, traffic, and addition of "fill" soil or gravel (Forman et al., 2003). As a result, soil properties along roadsides can be degraded and very different from those in the surrounding landscape.

Therefore, the research question is: How do the soil properties near the road edge compare with those further away from the road? The few previous studies located in New York, North Dakota, and Vermont reported increased bulk density and reduced water infiltration at the road-edge position compared with non-road edges, attributed to construction, traffic, and vibrations consolidating soils (Neher et al., 2013; Willmert, Osso, Twiss, & Langen, 2018). Similarly, soil pH, electrical conductivity (EC), and sodium (Na) can be higher near road edges than on the non-road edges (Bryson&Barker, 2002). The differences in soil chemical properties can be potentially due to mixing of soil horizons during construction and winter maintenance activities (Matthees, Hopkins, & Casey, 2018; Neher et al., 2013; Willmert et al., 2018). The majority of the few existing studies were from the eastern United States, with relatively higher precipitation compared with Nebraska (Bryson & Barker, 2002; Neher et al., 2013; Willmert et al., 2018). The study from North Dakota, although in a similar climate, was conducted after oil well access road removal and not along highways in the region (Matthees et al., 2018). Thus, the novelty of this work is

the investigation of soil properties along road edges in a much drier climate than the eastern United States, where ice storms, blizzards, and large shifts in weather patterns are common. The road segments were situated in grassland and agricultural regions, whereas the previous studies from the eastern United States were conducted in forested regions.

There exists a need for additional research to investigate the factors such as soil properties potentially limiting vegetation establishment along roadsides for different states and road conditions. Specifically, studies comprehensively evaluating soil physical and chemical properties along highways in Nebraska and the Great Plains region are unavailable. Knowledge of differences in soil properties between road edges and non-road edges is needed to implement mitigation and soil restoration strategies (Haan, Hunter, & Hunter, 2012). Thus, our study objectives were (a) to determine how soil physical and chemical properties change along a transect perpendicular to the road at six microtopographic positions (road edge, shoulder, side slope, ditch, backslope, and field edge) along two Nebraska highway segments and (b) to identify which soil physical and chemical properties exceeded the thresholds for plant growth. We hypothesized that soil properties would be above threshold levels for plant establishment and growth at the road-edge position compared with positions further from the road (Table 1).

Table 1. Ideal levels of some soil properties for plant agronomic growth (note that variability exists by soil type and plant species tolerance)

Soil property	Ideal level	Reference
Bulk density	<1.80 g cm^{-3}	Weil & Brady, 2017
Cone index	<2 MPa	Tormena et al., 1999
Electrical conductivity	<1.2 ds m^{-1}	Smith & Doran, 1996
Exchangeable Na percentage	<15	Tisdale et al., 1993
pH	6.5–7 for most agronomic crops	Tisdale et al., 1993
Organic matter	4–5%	Weil & Brady, 2017
Amount of macroaggregates	~66%	Ruis et al., 2017; Weil & Brady, 2017

2 Materials and methods

2.1 Description of the study sites

This study was conducted using two highway segments: L80E (40.79 N, −97.29 W) near Beaver Crossing in southeastern Nebraska and US-183 (41.65 N, −99.38 W) near Sargent in central Nebraska. These two highway segments were selected because the NDOT identified them as areas where they had difficulty establishing perennial vegetation. At the Beaver Crossing site, mean maximum temperature was 15.9 °C and mean annual precipitation was 743 mm. The soils in the area were predominantly Hastings silt loam (fine, smectitic, mesic udic Argiustolls), Crete silt loam (fine, smectitic, mesic pachic udertic Argiustolls), and Fillmore silt loam (fine, smectitic, mesic vertic Argialbolls). These soil series are generally very deep, silty soils with a clayey subsoil and nearly level to gentle slopes (<1% slope). The highway was two-lane with no structural dividers and was level within the landscape. Traffic volume was 1,600 vehicles d^{-1}.

At the Sargent site, the mean maximum temperature was 16.4 °C and mean annual precipitation was 661 mm. The soils in the area were predominantly Valentine fine sand (mixed, mesic typic Ustipsamments) with <21% slope, Elsmere loamy fine sand (sandy, mixed, mesic aquic Haplustolls) with <1% slope, and Tryon loamy fine sand (mixed, mesic typic Psammaquents) with 2% slope. These soils are generally deep sandy soils formed in alluvium or eolian sand, and the site was nearly level to moderately steep. The highway was two-lane with no structural dividers and was level within the landscape. Traffic volume was 1,385 vehicles d^{-1}; about 15% of the vehicles were heavy trucks. For both sites, road construction activities likely mixed the natural horizons; thus, the soils along the roadside likely do not directly classify into these soil series.

2.2 Experimental design

Field measurements and soil sampling were conducted in spring 2014 at six locations at each site (Figure 1). At the Beaver Crossing site, the locations were spaced every 3.2 km along a 17.7-km highway segment (Figure 1). At the Sargent site, the locations were every 1.6 km
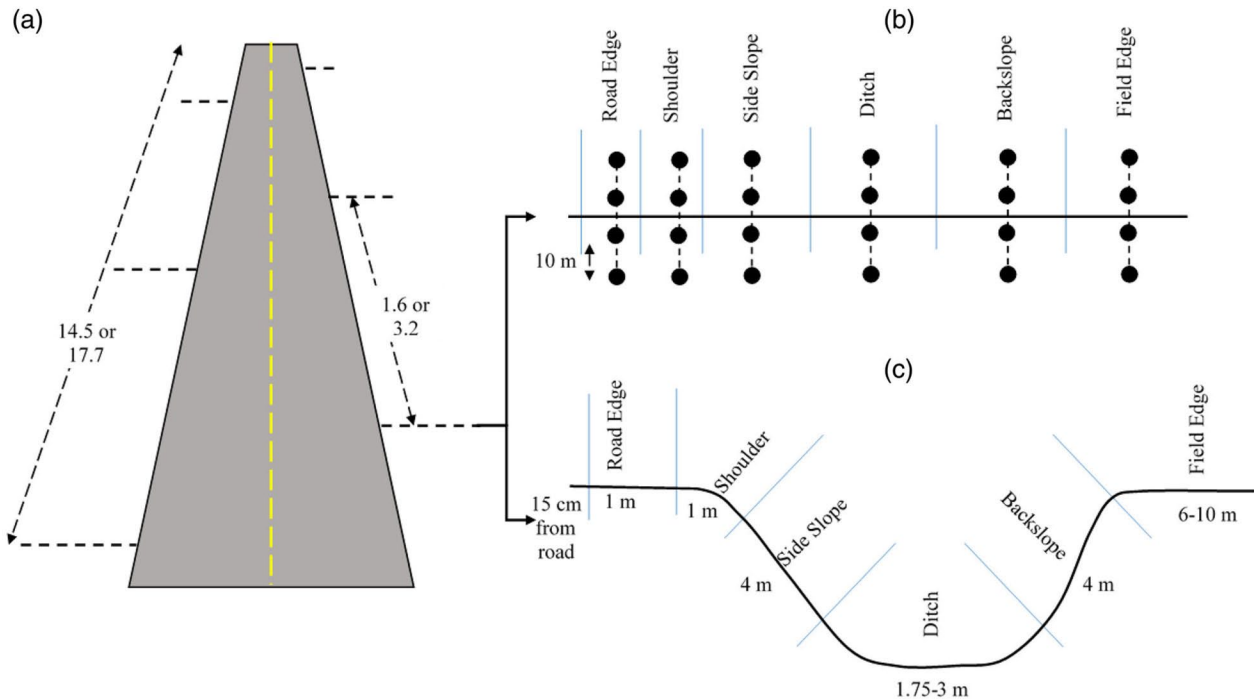
Figure 1. Sampling transects (dashed lines) where soil chemical and physical properties (a) were determined along highway segments near Beaver Crossing and Sargent, NE. At each sampling transect, six microtopographic positions (road edge, shoulder, side slope, ditch, backslope, and field edge (b) were sampled with each microtopographic position having four subsampling points along a 40 m transect (c). Diagram is not to scale. The number of samples collected was 144 per sampling depth per site, for a total of 576 samples for both sites

along a 14.5-km highway segment (Figure 1). Each of the six locations was subdivided by microtopographic position along a transect perpendicular to the road. These microtopographic positions were road edge, shoulder, side slope, ditch, backslope, and field edge (Figure 1). Each microtopographic position was subsampled along a 40-m transect parallel to the road at 10-m intervals (Figure 1). The number of samples collected was 144 per sampling depth per site, for a total of 576 samples. The ditch, backslope, and field-edge positions had abundant amounts of vegetation compared with other microtopographic positions, particularly the road-edge position, which had very sparse vegetation. The field-edge position, which was at the field edge, was agricultural land at the Beaver Crossing site and grazing lands at the Sargent site.

2.3 Soil measurements

Soil physical and chemical properties, including bulk density, cone index, sorptivity, wet aggregate stability, pH, EC, and concentrations of organic matter and other nutrients, were assessed at each site. These selected soil properties include indicators of compaction (bulk density and cone index), water infiltration (sorptivity), soil structure (wet aggregate stability), and nutrient status (chemical properties), which we predicted could be factors influencing vegetation establishment. We collected intact soil cores from the 0-to-20-cm depth at each subsampling point within the six microtopographic positions. To collect the intact cores, we used a 4.7-cm-diameter hammer-driven soil sampler with stainless steel liners for the road-edge and shoulder positions and a 2.2-cm-diameter zero-contamination sleeve sampler at all other positions. The hammer-driven sampler was used for the road-edge and shoulder positions because these positions were compacted and difficult to sample with standard soil probes. During construction, gravel and fill addition and subsequent compaction for stabilization of the road bed are common. Soil cores were transported to the laboratory in a cooler, sliced at 0-to-10-cm and 10-to-20-cm depths, and stored at 4 °C until analysis. At the time of soil core collection, we also collected bulk soil samples from each microtopographic position for the 0-to-10-cm and 10-to-20-cm depths. The bulk samples were air-dried for 72 h and passed through sieves with 8-mm openings by gently crushing larger aggregates.

Penetration resistance, a compaction indicator, was measured for the 0-to-10-cm and 10-to-20-cm depths using a hand penetrometer (Eijkelkamp, Giesbeek, The Netherlands) (Lowery & Morrison, 2002) at each subsampling point within the six microtopographic positions. Cone index, in MPa, was determined by dividing the penetrometer reading by the base area of the cone (1 cm^2). Because cone index is correlated with changes in soil water content, the measured values were adjusted to a common water content (Blanco-Canqui, Lal, Owens, Post, & Izaurralde, 2006; Busscher, Bauer, Camp, & Sojka, 1997).

Sorptivity, or initial water infiltration, was measured as described by Smith (1999) at each subsampling point for the road-edge, shoulder, side-slope, ditch, and field-edge positions. Steel rings (diameter, 9.8 cm) were driven into the soil to 2.5-cm depth while avoiding cracking

the soil surface. Prior to the ring insertion, any debris or plant material was removed without disturbing the soil surface. Water (75 ml) was poured into the ring, and the amount of time required for the water to infiltrate was recorded to obtain sorptivity (Smith, 1999).

A fraction of the soil sample from the cores was air-dried and analyzed for bulk density, a compaction indicator, and chemical properties. Bulk density was assessed by the core method (Blake and Hartge, 1986), pH and EC using a 1:1 water ratio (Whitney, 2011a), and concentration of organic matter by the loss-on-ignition method (Nelson & Sommers, 1996). The concentration of nitrate-N was assessed through KCl extraction and determination using the Cd reduction method (Gelderman & Beegle, 2011). Concentrations of K, Ca, Na, Mg, Zn, Fe, Mn, and Cu were determined through extraction with ammonium acetate or diethylenetriamine pentaacetate and assessment using atomic absorption spectrometry (Warncke & Brown, 2011; Whitney, 2011b). Concentrations of P and S were assessed using Mehlich III extraction and colorimetric reading of the extract on a spectrophotometer (Frank, Beegle, & Denning, 2011). The cation exchange capacity (CEC) was assessed using the methods described by Sumner and Miller (1996). The concentration of Cl was determined through the methods described by Adriano and Doner (1982), As through methods described by Ganje and Rains (1982), Cd and Ni by the methods of Baker et al. (1982), Cr by the methods of Reisenauer (1982), and Pb by the methods of Burau (1982).

Granulometric and particle size analysis (Gee & Bauder, 1986) was conducted on the bulk soil samples for each microtopographic position and depth from one transect on each side of the road. A soil subsample of 100–300 g, depending on sample size, was sieved through 4.75 mm. The contents of the 4.75-mm sieve were termed "gravel." The remainder of the sample was passed through 4-, 2.38-, and 2-mm sieves; washed to remove additional aggregates; dried at 105 °C; weighed; and termed "gravel 4–4.75 mm," "pebbles 2.38–4 mm," and "pebbles 2–2.38 mm." About 40 g of the 2-mm sieved sample were shaken for 16 h with 100 ml of 5% sodium hexametaphosphate solution. The soil texture was determined from this solution using the hydrometer method to determine the percentage of sand, silt, and clay (Gee & Bauder, 1986).

Using the bulk samples, soil wet-aggregate stability was determined by the wet-sieving method (Nimmo & Perkins, 2002) to describe the

soil structural quality. Air-dry soil samples were gently crushed to pass an 8-mm sieve. About 50 g of the 8-mm sieved soil was placed on top of sieves with 4.75- and 0.25-mm openings, saturated by capillarity with distilled water for 10 min, and then sieved in water using a mechanical wet sieving apparatus for another 10 min (Nimmo & Perkins, 2002). Soil aggregates remaining on each sieve were transferred to beakers and dried at 105 °C for 24 h. Samples were weighed, treated with sodium hexametaphosphate for 24 h, and washed through 0.053-mm sieves to correct for sand content (Nimmo & Perkins, 2002). The sand-free fraction of soil aggregates was then used to compute the fraction of macroaggregates (>0.25 mm).

2.4 Statistical analysis

Data were assessed by site (Beaver Crossing or Sargent) and depth (0–10 cm and 10–20 cm) for normality using the Shapiro–Wilk test (SAS Institute, 2019). Data that were nonnormally distributed were log transformed if needed, and residuals were checked for normality. Data were analyzed using ANOVA with the PROC MIXED in SAS for a completely randomized design with highway microtopographic positions (road edge, shoulder, side slope, ditch, backslope, and field edge) as the "treatment" and each location as "replication." Correlations among select soil properties were investigated using PROC CORR by site for the 0-to-10-cm depth. Differences were considered significant at the .05 probability level.

3 Results

3.1 Soil chemical properties

Soil chemical properties (including pH, EC, and concentrations of organic matter) and nutrients differed among microtopographic positions (road edge, shoulder, side slope, ditch, backslope, and field edge) at both sites (Table 2). At the Beaver Crossing site, soil pH at the 0-to-10-cm depth changed with microtopographic position in the order: road edge (8.40) > shoulder = side slope > ditch = backslope > field edge (5.90). At the Sargent site, soil pH for the same depth followed the order: road edge (8.20) = shoulder = side slope > ditch =

Table 2. Mean (SD) changes in nutrient concentrations and cation exchange capacity (CEC) with microtopographic position in the 0-to-10-cm soil depth at two highway segments near Beaver Crossing and Sargent, NE

	pH	EC dS m⁻¹	N	P	K	Ca	Mg	S mg kg⁻¹	Mn	Na	Zn	Fe	Cu	CEC cmol kg⁻¹
Beaver Crossing														
Road edge	8.4 (0.1)a	2.1 (0.6)a	2.1 (0.8)c	27.7 (3.5) ns	224 (69)c	2,494 (335)c	163 (49)c	24.2 (9.1) ns	6.6 (1.1)b	1851 (253)a	2.1 (0.8) ns	15.5 (2.6)c	1.7 (0.3)a	22.4 (1.5)a
Shoulder	7.9 (0.1)b	1.7 (0.7)b	2.6 (1.7)c	22.7 (2.4)	287 (39)c	2,976 (386)b	279 (51)b	26.2 (15.0)	7.7 (3.5)b	1114 (404)b	1.7 (0.8)	15.8 (3.8)c	0.9 (0.2)b	22.8 (2.0)a
Side slope	7.6 (0.2)b	0.6 (0.1)c	10.1 (5.2)ab	34.5 (8.8)	419 (66)b	3,443 (396)a	280 (41)b	19.4 (5.2)	9.8 (5.7)b	188 (71.0)c	3.1 (0.9)	26.1 (10.8)b	0.9 (0.1)b	21.4 (2.5)ab
Ditch	6.8 (0.2)c	0.5 (0.1)c	6.9 (5.1)b	30.5 (14.6)	635 (63)a	2,582 (338)bc	479 (123)a	25.2 (2.7)	18.2 (13.9)ab	78.6 (32.8)d	3.9 (3.8)	77.5 (68.2)a	1.4 (0.4)a	19.2 (2.4)bc
Back slope	6.8 (0.3)c	0.4 (0.1)c	6.7 (4.1)b	37.5 (25.9)	648 (84)a	2,373 (421)c	476 (112)a	26.7 (5.4)	22.2 (13.6)a	33.1 (17.1)e	1.9 (0.6)	45.6 (18.1)a	1.0 (0.2) b	18.3 (2.4) bc
Field edge	5.9 (0.6)d	0.3 (0.1)c	20.9 (15.3)a	40.6 (23.0)	506 (58)b	1,883 (302)d	307 (67)b	22.7 (5.4)	27.7 (13.3)a	22.8 (8.1)e	1.8 (0.6)	57.9 (32.5)a	0.9 (0.2)b	17.5 (2.1)c
Sargent														
Road edge	8.2 (0.3)a	3.6 (0.3)a	1.9 (0.5)b	29.8 (6.8)a	249 (46)d	2,080 (282)b	202 (59)c	27.5 (8.1)a	8.2 (3.2)b	1,984 (157)a	2.1 (1.7)a	20.4 (7.2)bc	1.6 (0.3)a	21.4 (1.8)ab
Shoulder	8.2 (0.2)a	1.4 (0.9)b	1.7 (1.2)b	24.5 (8.0)ab	271 (58)d	2,761 (160)a	333 (76)b	26.5 (13.5)ab	8.0 (1.7)b	1,209 (486)b	1.3 (0.8)ab	17.5 (6.5)c	1.0 (0.2)b	22.5 (2.4)a
Side slope	8.2 (0.3)a	0.5 (0.1)b	2.7 (1.6)b	30.3 (9.6)a	430 (52)bc	2,927 (322)a	434 (85)b	18.3 (3.4)b	8.5 (1.6)b	292 (109)c	1.0 (0.3)ab	27.8 (13.5)b	1.0 (0.1)b	20.7 (2.6)ab
Ditch	7.8 (0.2)ab	0.4 (0.1)b	2.1 (1.2)b	27.1 (18.0)ab	514 (125)ab	2,723 (711)a	624 (214)a	18.9 (1.4)ab	12.7 (6.6)ab	104 (52.2)d	1.2 (1.2)ab	38.5 (22.4)ab	1.3 (0.4)ab	20.8 (5.7)ab
Back slope	7.6 (0.3)ab	0.3 (0.04)b	2.4 (1.7)b	15.0 (6.5)ab	587 (150)a	2,885 (298)a	661 (101)a	21.1 (5.2)ab	13.4 (5.1)ab	40.3 (18.3)e	0.6 (0.2)b	35.8 (8.9)ab	1.1 (0.3)b	22.5 (2.1)a
Field edge	7.5 (0.4)b	0.3 (0.1)b	19.6 (20.0)a	17.9 (14.7)b	373 (53)c	1,910 (275)b	336 (81)b	19.7 (4.5)ab	23.0 (11.8)a	25.6 (9.3)e	0.8 (0.4)ab	58.4 (26.7)a	0.9 (0.2)b	19.1 (0.9)b

Microtopographic positions with the same lowercase letter within a column and site are not statistically significant at $p < .05$. ns denotes nonsignificant.

backslope > field edge (7.49). At both sites, trends in soil pH for the 10-to-20-cm depth were similar to the upper depth. Changes in EC at the Beaver Crossing site for the 0-to-10-cm depth paralleled the soil pH changes in the order: road edge (2.08 dS m^{-1}) = shoulder > side slope = ditch > field edge (0.33 dS m^{-1}). The backslope position EC was similar to the side-slope, ditch, and field-edge positions. The response was similar at the Sargent site, but EC was higher at the road-edge position (3.56 dS m^{-1}). At both sites, differences in EC among microtopographic positions were similar at the 10-to-20-cm depth (Supplemental Table S1).

Soil nutrient concentrations of N, K, Mg, Mn, and Fe were lower at the road edge than at the field-edge position (Table 2) for the 0-to-10-cm depth at both sites. At the Beaver Crossing site, concentrations of Ca, Na, and Cu were higher at the road-edge position than at the field-edge position. The sideslope, ditch, and backslope positions had the highest concentrations of K, Ca, Mg, and Fe. The CEC generally decreased with increasing distance from the road-edge position. At the Sargent site, concentrations of P, Na, and Cu were higher, but those of N, K, Mg, Mn, and Fe were lower, at the road edge than at field-edge position for the 0-to-10-cm depth. The sideslope, ditch, or backslope positions had the highest K, Ca, and Mg concentration. Organic matter (Table 3) concentration was lowest at the road-edge position and highest at the sideslope, ditch, and backslope positions at the Beaver Crossing site for the 0-to-10-cm depth. Similarly, at the Sargent site, organic matter was lower at the road edge than at the field-edge position. At both sites, organic matter concentration generally increased as the distance from the road increased.

At the 10-to-20-cm depth,Mg, Mn, Zn, Fe, and Cu concentrations did not vary with microtopographic position at both sites (Supplemental Table S1). Concentrations of Ca and Na and CEC were higher along the road-edge position than along the field-edge position at the Beaver Crossing site. Also, both Ca and Na concentration decreased with increasing distance from the road. Likewise, at the Sargent site, the concentrations of Ca, S, and Na and CEC were higher along the road-edge position than along the field-edge position. The concentration of Na, similar to the surface depth, decreased with increasing distance from the road. At both sites, the road-edge position had lower organic matter concentration than the field-edge position for the 10-to-20-cm depth (Supplemental Table S2).

Table 3. Mean (SD) changes in organic matter concentrations and select soil physical properties with microtopographic position in the 0-to-10-cm soil depths at two highway segments near Beaver Crossing and Sargent, NE

Position	Organic matter g kg^{-1}	Bulk density Mg m^{-3}	Cone index MPa	Macroaggregates % s	Sorptivity cm$^{-1/2}$
Beaver Crossing					
Road edge	16.3 (0.4)d	2.0 (0.05)a	6.8 (2.1)a	7.5 (7.4)c	0.2 (0.1)c
Shoulder	24.4 (0.5)c	1.8 (0.18)b	5.1 (1.9)b	60.9 (22.8)b	0.2 (0.1)c
Side slope	45.1 (0.3)a	1.4 (0.05)c	2.1 (0.6)c	87.4 (4.0)a	0.9 (0.3)a
Ditch	48.9 (0.6)a	1.2 (0.18)d	1.1 (0.2)c	81.6 (9.0)a	0.9 (0.3)a
Back slope	49.0 (0.7)a	1.6 (0.11)cd	1.3 (0.2)c	86.1 (5.5)a	na
Field edge	33.9 (0.5)b	1.4 (0.29)cd	1.4 (0.5)c	64.6 (9.3)b	0.4 (0.2)b
Sargent					
Road edge	18.7 (0.2)b	1.7 (0.04)a	9.3 (1.1)a	15.5 (9.2)d	0.3 (0.2)c
Shoulder	18.6 (0.3)b	1.5 (0.16)b	7.2 (1.6)b	23.3 (12.3)dc	0.6 (0.4)b
Side slope	24.5 (0.3)b	1.5 (0.11)b	5.0 (1.8)c	33.6 (16.8)c	0.6 (0.2)b
Ditch	26.3 (0.6)b	1.4 (0.13)bc	4.9 (0.6)c	50.9 (26.1)b	0.8 (0.3)b
Back slope	32.0 (0.4)ab	1.3 (0.10)bc	3.2 (2.2)d	60.9 (18.3)ab	na
Field edge	39.1 (0.2)a	1.3 (0.16)bc	4.4 (3.6)cd	63.5 (36.9)a	1.2 (0.6)a

Microtopographic positions with the same lowercase letter within a column and site are not statistically significant at *p* < .05. ns, nonsignificant.

Chloride and heavy metal concentrations were assessed on one transect from each side of the road; thus, no statistical analysis was conducted, and we only discuss numerical differences (Supplemental Table S3). At the Beaver Crossing site, there were numerical differences among positions for Pb only, where Pb was highest at the road-edge position. Chloride and all other heavy metals were generally similar in concentration among positions. At the Sargent site, there were numerical differences among positions for Cl, Cr, and Pb concentrations. Arsenic and Cd concentrations were similar across microtopographic position. Chloride concentration was highest at the road-edge, side-slope, and shoulder positions, generally decreasing with distance from the road. Chromium and Pb concentrations were highest at the shoulder positions, whereas all other positions were similar in concentration. Chloride concentrations were much higher at the Sargent site, likely due to the differences in soil texture and climatic conditions.

3.2 Soil physical properties

Soil bulk density and cone index (compaction indicators), amount of water-stable macroaggregates (an indicator of changes in soil structure), and sorptivity (initial water infiltration) differed among the six microtopographic positions at both sites and depths (0–10 cm and 10–20 cm) (Table 3). Bulk density decreased from the road edge (1.94 Mg m⁻³) to the ditch (1.23 Mg m⁻³). The backslope and field-edge positions were similar to the side-slope and ditch positions at the 0-to-10-cm depth at the Beaver Crossing site, whereas at the same depth bulk density was higher at the road-edge position (1.65 Mg m⁻³) compared with all other microtopographic positions (mean of all other positions, 1.38 Mg m⁻³) at the Sargent site. For the 10-to-20-cm depth, bulk density generally decreased with increasing distance from the road edge at both sites.

Similar to bulk density, cone index was highest at the road-edge position (6–9.5 MPa) and generally decreased with increasing distance from the road at both sites and depths. The lowest cone index values occurred at the side-slope, ditch, backslope, and field-edge positions at the Beaver Crossing site (mean, 1.6 MPa) and at the backslope and field-edge positions at the Sargent site (mean, 4.1 MPa). Macroaggregate amount was the lowest at the road-edge position (7%) and highest at the side-slope, ditch, and backslope positions (85%) at the Beaver Crossing site for the 0-to-10-cm depth. For the same depth, macroaggregate amount was lowest at the road-edge position (15%) and highest at the field-edge position (63%) at the Sargent site. For the 10-to-20-cm depth, differences were similar to the upper depth at both sites (Supplemental Table S2).

Likewise, at both sites, soil sorptivity was lowest near the road and highest further away from the road. Sorptivity at the Beaver Crossing site was lowest at the road-edge and shoulder positions (0.21 cm s⁻¹⁄²) and highest at the side-slope and ditch positions (0.9 cm s⁻¹⁄²). At the Sargent site, soil sorptivity was the lowest at the road-edge position (0.25 cm s⁻¹⁄²) and highest at the field-edge position (1.23 cm s⁻¹⁄²).

At Beaver Crossing, for the 0-to-10-cm depth, gravel >4.75 mm and gravel 4–4.75 mm were highest at the road-edge, ditch, and side-slope positions and minimal on the backslope and field-edge positions (Supplemental Table S4). Pebbles 2.38–4 mm and 2–2.38 mm

generally decreased with increasing distance from the road. Soil textures were loam at the roadedge, side-slope, and ditch positions and silt loam at the shoulder, backslope, and field-edge positions. At Sargent, for the same depth, of the coarse material, gravel >4.75 mm and pebbles 2.38–4 mm were most common on the road-edge, shoulder, and side-slope positions. Coarse material was generally not present in the ditch, backslope, and field-edge positions. Soil texture was generally sandy near the road and silt loam to loam from the side-slope to field-edge positions. At Beaver Crossing for the 10-to-20-cm depth, gravel and pebbles were typically present at the road-edge, shoulder, side slope, and ditch positions and absent at the backslope and field-edge position. For the same depth at Sargent, gravel >4.75 mm and pebbles 2.38–4 mm were most common in the coarse material, particularly at the road-edge position. Soil texture was sandy at the road-edge position and loam to silt loam beginning at the shoulder position.

3.3 Correlations among soil properties

We studied correlations of soil properties across microtopographic positions for the 0-to-10-cm depth by site (Table 4). At the Beaver Crossing site, bulk density and cone index were strongly and negatively correlated with the amount of macroaggregates and organic matter, indicating that as soil compaction increased, both macroaggregation and organic matter accumulation decreased (Table 4). Similarly, an increase in Na concentration resulted in a reduced amount of macroaggregates. Soil sorptivity declined as bulk density, cone index, and Na concentration increased, but it improved with an increase in organic matter and in the amount of macroaggregates. Soil pH increased with increasing Na and decreasing organic matter concentrations. At the Sargent site, correlations were similar to those at the Beaver Crossing site except that sorptivity was not correlated with bulk density and organic matter and Na concentrations.

4 Discussion

Soil chemical properties such as Na concentration, EC, and pH were above optimum (Tables 1 and 2). The high Na concentration at the

Table 4. Pearson correlation coefficients among select soil properties for the 0-to-10-cm depth along two highway segments near Beaver Crossing and Sargent, NE

	Bulk density Mg m⁻³	Cone index MPa	Macro-aggregates %	Sorptivity s cm⁻½	pH dS m⁻¹	Electrical conductivity g kg⁻¹	Organic matter mg kg⁻¹	Na concentration
Beaver Crossing								
Bulk density (Mg m⁻³)	1							
Cone index (MPa)	0.84**	1						
Macroaggregates (%)	−0.68**	−0.59**	1					
Sorptivity (s cm⁻½)	−0.58*	−0.57*	0.57**	1				
pH	0.61**	0.73**	−0.21	−0.33	1			
Electrical conductivity (dS m⁻¹)	0.79**	0.80**	−0.60**	−0.61*	0.73**	1		
Organic matter (g kg⁻¹)	−0.81**	−0.76**	0.77**	0.54*	−0.53**	−0.77**	1	
Na concentration (mg kg⁻¹)	0.84**	0.87**	−0.69**	−0.63*	0.78**	0.96**	−0.83**	1
Sargent								
Bulk density (Mg m⁻³)	1							
Cone index (MPa)	0.39*	1						
Macroaggregates (%)	−0.41*	−0.70**	1					
Sorptivity (s cm⁻½)	−0.40	−0.69**	0.76**	1				
pH	0.61**	0.23	−0.36**	−0.29	1			
Electrical conductivity (dS m⁻¹)	0.64**	0.43**	−0.46**	−0.34	0.67**	1		
Organic matter (g kg⁻¹)	−0.71**	−0.38*	0.32*	0.12	−0.69**	−0.63**	1	
Na concentration (mg kg⁻¹)	0.68**	0.48**	−0.49**	−0.39	0.70**	0.98**	−0.33*	1

*Significant at the .05 probability level.
**Significant at the .01 probability level.

road-edge position followed by the shoulder and side-slope positions is likely due to deicing salt application during winter road management. The estimated quantity of rock salt used for road deicing in the United States was about 24.5 million t in 2010 (Lilek, 2017), with application rates ranging from 14 to 169 kg km⁻¹ of lane per pass (Blackburn and Associates, 2014). Although other deicing agents, such as $CaCl_2$ can be used, rock salt (NaCl) is the most commonly used (Blackburn and Associates, 2014). The accumulation of Na at these locations of the roadway can be toxic to sensitive plants and can reduce soil-water potential. Further, as shown by the correlations in Table 3, the high Na concentration can disperse soil aggregates, leading to smaller aggregate size, low water infiltration, and higher levels of compaction. At the road-edge position of these sites, the exchangeable Na concentration was about 36% at Beaver Crossing and 17% at Sargent, which is above the 15% exchangeable Na threshold for salt-sensitive plants (Tisdale, Nelson, Beaton, & Havlin, 1993). Sodium causes issues within

the soil and within plants as well. For example, high levels of Na can alter stomatal function and nutritional balance with Ca and K (Tavakkoli, Rengasamy, & McDonald, 2010). Our results agree with those of a study in New York that showed 2.3 times higher Na concentrations near the road than the equivalent backslope, which was attributed to road salt application (Willmert et al., 2018). In urban soils, Na concentrations are generally 100 mg kg^{-1} higher near commercial or transportation centers (214 mg kg^{-1}) than near residential or parkland areas (about 100 mg kg^{-1}) (Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). It should also be noted that urban areas with high salt (commercial and transportation) concentrations are substantially lower than our road-edge Na concentrations (Table 2) (Pouyat et al., 2007).

The high EC along the road edge (Table 2) is likely driven in part by the high Na concentration and is related to the high pH (Equiza, Calvo-Polanco, Cirelli, Señorans, & Wartenbe, 2017). For example, across sites, the EC was 1.7–3.0 times above the threshold level (1.2 dS m^{-1}) that can limit the growth of plants (Smith & Doran, 1996). Our results of higher EC along the road edge are in line with those in North Dakota and New York (Matthees et al., 2018; Willmert et al., 2018). Therefore, based on our data, the concentration of Na followed by EC can be the primary soil chemical concerns for plant establishment and growth in these soils.

The high soil pH (>8) at the road edge may indicate lower availability of some nutrients and is outside the optimum pH range of 6.5–7.0 for most plants (Tisdale et al., 1993). One concern with the high pH and Ca concentration along the road edge is the amount of available Fe. Soils with pH levels of 7.3–8.5 are more likely to have plants showing Fe deficiency symptoms (Tisdale et al., 1993). However, the Fe concentrations of the soils along these two roadsides are above sufficiency thresholds (>4.5 mg kg^{-1}). Previous studies in North Dakota and New York also showed decreasing pH with increasing distance from the road (Matthees et al., 2018; Willmert et al., 2018). In urban soils, soil pH may not be above 7, although levels of Ca may be high in commercial or transportation and industrial centers compared with parks and residential areas (Pouyat et al., 2007). Thus, it appears that, although pH is high, other roadside soil properties appear to have much more negative effects on plant growth.

Results from the two road edges studied showed that compaction

parameters (bulk density and particularly cone index) appear to be the leading soil physical properties limiting plant establishment and growth along the roadside coupled with aggregation, water infiltration, and the previously discussed chemical properties, all or most of which are interrelated (Table 2) (Equiza et al., 2017). For example, bulk density was 1.09 times higher at the road edge and 1.03 times higher at the shoulder position than the threshold level of 1.8 Mg m^{-3} (Table 1) (Weil & Brady, 2017) at the Beaver Crossing site. Other microtopographic positions were below the threshold bulk density level at the Beaver Crossing site, and none of the microtopographic positions was above the threshold bulk density level at Sargent. Although the 1.03 to 1.08 times higher bulk density at Beaver Crossing may not alone restrict plant growth, other properties, such as the adverse chemical properties (Tables 1 and 2), may have greater adverse effects on plant growth.

Similarly, cone index values for the road edge and shoulder exceeded the threshold value of 2 MPa (Table 1) (Tormena, Silva, & Libardi, 1999) by at least three times at Beaver Crossing and five times at Sargent. The road-edge position adjacent to the road (about 1 m) was highly compacted by road grading during construction and off-road vehicle traffic following construction, which can explain the reduced vegetation establishment along the roadsides. Our results agree with a study in New York where the road edge with reduced vegetation had higher bulk density compared with the soil in the backslope position (Willmert et al., 2018).

The amount of macroaggregates (<15%) at the road edge of both sites was much lower than a threshold level of macroaggregates (66%) observed in "ideal" agricultural soils with 4– 5% organic matter (Table 1) (Ruis, Blanco-Canqui, Jasa, Ferguson, & Slater, 2017; Weil & Brady, 2017). The amount of macroaggregates and water infiltration were highest at the ditch and field edge, where we observed the tallest and most dense vegetation. Also, as shown by the correlations in Table 6, the decrease in sorptivity and the amount of aggregates with an increase in compaction parameters indicate that high levels of compaction can directly affect water infiltration and structural quality.

The low amount of macroaggregates and low rate of water infiltration combined with limited vegetation cover at the road-edge position may cause increased rates of runoff and losses of sediment and

nutrients, thereby reducing water quality and contributing to further environmental degradation (Barrett et al., 2004; Streeter, Schilling, St. Clair, & Demanett, 2019). Vegetation cover along roads have the potential to perform functions similar to filter strips. Our findings of lower water infiltration and aggregation near the road edge are similar to studies on loamy soils in Virginia and North Dakota, which reported that road edges and areas with construction traffic can have lower water infiltration (Matthees et al., 2018) and aggregation (Chen, Day, Wick, & McGuire, 2014) than non-road edge or nontrafficked locations.

Concentrations of Cl and heavy metals were generally similar among the microtopographic positions, with some exceptions. The first exception is Cl at Sargent, which was highest at the road-edge, shoulder, and side-slope positions and could be a contributing factor to poor vegetation establishment at that site because high Cl concentrations degrade chlorophyll, resulting in poor growth under saline conditions (Tavakkoli et al., 2010). The second exception is Pb, which was highest at the road-edge position at the Beaver Crossing site and highest at the shoulder position at Sargent. Compared with urban soils, the concentration of Pb was much lower (Pouyat et al., 2007). The levels of other heavy metals at other microtopographic positions were likely not issues for plants because similar concentrations were observed where plant growth was abundant (i.e., the ditch), and none exceeded the toxicity limits in the established literature (Kabata-Pendias, 2011). Despite this fact, the high levels of Na and Cl at the road edge can increase the mobility of heavy metals, thus leading to the potential for contamination of ground and surface waters (Schuler & Relyea, 2018).

Understanding how key soil fertility and physical properties differ among different microtopographic roadside positions is an important first step to identifying factors affecting roadside vegetation establishment. The use of remediation measures (Hillhouse, Schacht, Soper, & Weinhold, 2018; Litalien & Zeeb, 2020) and identification of salt- and compaction-tolerant plants (Friell, Watkins, & Horgan, 2012; Hilvers, Hopkinson, & Davis, 2017; Johnson, 2008) need to be investigated to successfully establish roadside vegetation in Nebraska.

5 Conclusion

This study identified several properties that can limit vegetation establishment and growth along roadsides by comparing soil properties among microtopographic positions (road edge, shoulder, side slope, ditch, backslope, and field edge). Compaction, Na concentration, EC, and pH were highest at the road-edge position and decreased with increasing distance from the road; these have cascading effects on plant establishment and growth. Likewise, water infiltration and aggregation were lowest at the road-edge position but improved with distance from the road. Compaction parameters, Na concentration, and EC were above the threshold levels for compaction, sodicity, and salt-sensitive plants. Based on the correlation analysis, high levels of compaction reduced the amount of macroaggregates, water infiltration, and organic matter, whereas high Na concentration reduced the amount of macroaggregates, reduced water infiltration, and increased EC. Mitigation of compaction and sodic conditions needs to be considered if delivery of ecosystem services from roadside vegetation is a priority. This study identified compaction and Na concentration as two of the leading soil physical and chemical properties that may be limiting vegetation establishment along roadsides in Nebraska.

Conflict of interest The authors have declared there are no conflicts of interest.

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Supporting information follows.

Supplementary Table 1. Mean (SD) changes in nutrient concentrations and cation exchange capacity (CEC) with micro-topographic position in the 0 to 10 and 10 to 20 cm soil depths at two highway segments near Beaver Crossing and Sargent, NE. Micro-topographic positions with the same lowercase letter within a column and site are not statistically significant at $p < 0.05$. ns denotes non-significant.

	pH	EC	N	P	K	Ca	Mg	S	Mn	Na	Zn	Fe	Cu	CEC
		(dS m⁻¹)					(mg kg⁻¹)							(cmol kg⁻¹)
					10 to 20 cm soil depth									
					Beaver Crossing									
Road edge	7.9 (0.5) a	2.5 (2.7) a	5.6 (5.0) ns	21.8 (10.8) ab	342 (128) b	4445 (701) a	351 (206) ns	42.8 (25.5) a	6.5 (2.0) ns	1365 (774) a	1.4 (1.2) ns	13.9 (5.9) ns	0.8 (0.2) ns	32.0 (7.4) a
Shoulder	7.8 (0.2) ab	1.9 (1.3) b	8.6 (7.8)	36.9 (18.3) a	500 (75) a	3660 (491) ab	394 (115)	16.2 (8.5) b	6.2 (1.2)	452 (413) b	1.9 (1.5)	10.8 (3.8)	0.8 (0.1)	24.8 (3.9) b
Side slope	7.5 (0.3) b	0.5 (0.3) c	5.7 (3.4)	36.0 (22.0) a	511 (30) a	3564 (698) ab	365 (64)	16.9 (7.9) b	6.2 (1.7)	194 (194) c	1.9 (1.2)	11.3 (2.8)	0.8 (0.1)	23.0 (3.3) b
Ditch	6.8 (0.5) c	0.3 (0.1) c	7.7 (4.1)	20.8 (12.4) ab	489 (70) a	3143 (835) bc	367 (84)	14.8 (7.9) b	6.7 (3.1)	54.7 (28.3) d	1.1 (0.3)	15.2 (11.4)	0.8 (0.2)	20.3 (4.5) bc
Back slope	6.6 (0.6) c	0.3 (0.1) c	5.7 (4.0)	13.5 (7.6) b	454 (86) a	2971 (1067) bc	382 (15)	14.3 (7.3) b	7.1 (3.1)	21.7 (107) e	0.9 (0.3)	16.1 (9.6)	0.8 (0.2)	19.3 (5.7) bc
Field edge	5.5 (0.2) d	0.3 (0.1) c	6.0 (3.9)	8.5 (4.1) b	459 (156) a	2322 (530) c	328 (112)	18.0 (10.7) b	7.5 (1.3)	12.3 (6.1) e	1.6 (0.9)	13.7 (4.8)	0.7 (0.03)	15.6 (3.7) c
					Sargent									
Road edge	8.2 (0.2) a	2.0 (0.8) a	4.7 (2.8) ab	17.3 (5.8) ab	398 (74) ns	4243 (811) a	308 (91) ns	51.7 (57.9) a	5.4 (0.9) ns	741 (351) a	1.2 (0.7) bc	15.6 (5.6) ns	0.8 (0.2) ns	28.0 (4.3) a
Shoulder	8.1 (0.4) ab	1.1 (1.0) b	6.6 (7.4) ab	35.0 (27.1) ab	402 (103)	3233 (685) b	363 (105)	15.5 (4.0) b	7.2 (3.2)	329 (233) b	2.2 (1.5) ab	14.9 (5.3)	0.8 (0.1)	21.7 (4.5) b
Side slope	8.2 (0.3) ab	0.6 (0.4) bc	7.8 (4.9) a	39.9 (33.5) a	432 (58)	3069 (655) b	367 (71)	17.4 (9.5) b	5.2 (1.0)	181 (127) b	2.7 (1.8) a	13.7 (4.5)	0.8 (0.1)	20.3 (4.0) b
Ditch	8.0 (0.6) ab	0.3 (0.1) c	3.9 (3.5) ab	17.3 (10.8) b	444 (91)	3261 (1057) b	390 (108)	15.3 (11.8) b	6.6 (4.1)	67.1 (34.1) c	0.7 (0.1) c	13.0 (5.0)	0.8 (0.2)	21.0 (5.6) b
Back slope	7.7 (0.7) bc	0.2 (0.1) c	2.7 (1.3) b	10.8 (5.4) b	418 (58)	2885 (1067) b	421 (148)	13.0 (8.5) b	7.2 (4.0)	19.0 (5.2) d	0.6 (0.1) c	14.4 (6.9)	0.9 (0.2)	19.1 (5.8) b
Field edge	7.5 (0.4) bc	0.2 (0.1) c	3.0 (1.0) ab	7.9 (4.9) b	411 (149)	2371 (609) b	341 (76)	14.7 (7.9) b	8.1 (2.9)	12.4 (7.1) d	0.7 (0.2) c	12.4 (4.7)	0.7 (0.04)	15.8 (3.6) b

Supplementary Table 2. Mean (SD) changes in organic matter concentrations and select soil physical properties with micro-topographic position in the 0 to 10 and 10 to 20 cm soil depths at two highway segments near Beaver Crossing and Sargent, NE. Micro-topographic positions with the same lowercase letter within a column and site are not statistically significant at $p < 0.05$. ns denotes non-significant.

	Organic Matter (g kg^{-1})	Bulk Density (Mg m^{-3})	Cone Index (MPa)	Macroaggregates (%)
		10 to 20 cm soil depth		
		Beaver Crossing		
Road edge	14.4 (0.7) d	2.0 (0.05) a	5.9 (1.8) a	16.6 (13.0) c
Shoulder	20.7 (0.7) cd	1.7 (0.13) b	4.3 (1.6) a	45.4 (4.5) b
Side slope	22.9 (0.9) bc	1.7 (0.07) b	2.1 (0.8) b	74.7 (2.7) a
Ditch	18.7 (1.1) cd	1.4 (0.23) c	1.4 (0.3) b	71.0 (4.5) a
Back slope	26.6 (1.4) ab	1.5 (0.04) c	1.6 (0.2) b	75.5 (2.8) a
Field edge	28.4 (0.9) a	1.4 (0.22) c	2.0 (0.4) b	51.1 (2.0) b
		Sargent		
Road edge	18.1 (0.8) b	1.6 (0.08) a	9.7 (0.2) a	18.5 (15.5) d
Shoulder	20.3 (0.8) ab	1.6 (0.10) a	8.2 (2.9) ab	36.4 (26.0 c
Side slope	26.5 (1.2) a	1.5 (0.16) ab	6.6 (2.2) bc	46.1 (26.7) b
Ditch	17.7 (0.4) b	1.5 (0.04) a	5.9 (1.1) cd	51.8 (22.7) b
Back slope	20.8 (0.7) ab	1.3 (0.12) c	3.7 (2.5) d	50.9 (20.8) b
Field edge	25.7 (0.4) ab	1.4 (0.07) bc	5.3 (3.7) d	64.4 (24.8) a

Supplementary Table 3. Mean (SD) chloride and heavy metal concentrations for the 0 to10 cm depth along two highway segments near Beaver Crossing and Sargent, NE. No statistical analysis was run to compare concentrations at different road edge segments because only two transects were analyzed.

	Chloride	Chromium	Nickel	Arsenic	Cadmium	Lead
			(mg kg^{-1})			
			Beaver Crossing			
Road edge	17.0 (0.6)	47.2 (2.4)	18.3 (8.1)	4.7 (0.1)	0.4 (0)	59.2 (63.3)
Shoulder	30.6 (4.9)	36.6 (6.7)	20.0 (4.8)	7.3 (1.4)	0.4 (0)	16.7 (1.8)
Side Slope	26.4 (14.7)	44.8 (1.6)	20.2 (1.6)	6.0 (0.4)	0.4 (0.1)	14.9 (4.0)
Ditch	39.0 (9.7)	35.9 (10.9)	19.1 (5.1)	6.7 (0.80)	0.3 (0.04)	14.6 (0.3)
Backslope	38.7 (0.8)	39.1 (5.7)	21.0 (1.6)	7.6 (0.02)	0.3 (0.01)	15.8 (1.0)
Field Edge	23.5 (0)	40.7 (3.2)	21.2 (2.1)	7.8 (0.7)	0.3 (0.03)	17.1 (1.5)
			Sargent			
Road edge	1935 (2729)	32.4 (3.6)	15.0 (2.6)	3.5 (0.6)	0.15 (0)	7.7 (1.9)
Shoulder	448 (624)	51.6 (10.5)	16.5 (4.4)	3.4 (0.5)	0.15 (0.01)	76.1 (86.8)
Side Slope	217 (136)	28.3 (0.4)	13.4 (1.7)	3.1 (0.9)	0.16 (0.03)	13.0 (3.3)
Ditch	14.0 (3.6)	27.3 (1.1)	11.7 (0.4)	4.0 (0.6)	0.19 (0.01)	13.4 (3.4)
Backslope	9.9 (3.0)	25.0 (1.1)	10.6 (0.1)	4.1 (0.8)	0.19 (0.04)	11.9 (3.9)
Field Edge	10.7 (7.6)	25.0 (0.02)	10.8 (0.4)	4.4 (0.5)	0.22 (0.09)	12.3 (4.2)

Supplementary Table 4. Mean (SD) coarse material (gravel, pebbles), sand, silt, clay percentages and soil texture for the 0 to10 cm and 10 to 20 cm depths along two highway segments near Beaver Crossing and Sargent, NE.

	Gravel >4.75 mm	Gravel 4 to 4.75 mm	Pebbles 2.38 to 4 mm	Pebbles 2 to 2.38 mm	Sand	Silt	Clay	Soil Texture
				(%)				
			0 to 10 cm					
			Beaver Crossing					
Road edge	11.9 (7.1)	5.9 (0.1)	18.7 (0.6)	7.7 (0.6)	34.6 (8.7)	42.4 (3.5)	23.0 (5.2)	Loam
Shoulder	3.4 (0.04)	3.5 (1.9)	11.5 (7.8)	8.2 (2.3)	25.2 (13.0)	52.0 (4.7)	22.9 (8.3)	Silt loam
Side Slope	8.5 (5.5)	3.6 (1.5)	7.8 (2.9)	5.9 (0.2)	33.5 (6.8)	42.4 (0.5)	24.2 (6.3)	Loam
Ditch	10.9 (13.3)	5.9 (1.4)	8.0 (0.6)	6.8 (0.5)	31.5 (11.0)	44.2 (11.7)	24.3 (0.7)	Loam
Backslope	1.0 (1.4)	0.4 (0.6)	5.2 (7.3)	4.6 (6.5)	22.3 (8.8)	56.4 (16.3)	21.4 (7.5)	Silt loam
Field Edge	0	0	0	0	25.4 (12.7)	51.6 (4.2)	23.0 (8.5)	Silt loam
			Sargent					
Road edge	6.2 (3.4)	2.2 (3.0)	20.8 (5.8)	6.1 (1.5)	67.4 (8.5)	26.0 (5.1)	6.6 (3.3)	Sandy loam
Shoulder	12.2 (13.7)	1.4 (1.9)	14.8 (5.9)	5.0 (1.3)	51.4 (13.1)	27.3 (22.1)	21.4 (9.1)	Sandy clay loam
Side Slope	0.5 (0.4)	2.9 (2.6)	14.3 (13.5)	4.7 (3.7)	46.6 (23.0)	40.7 (14.4)	12.7 (8.5)	Loam
Ditch	0.05 (0.07)	0.2 (0.2)	1.5 (0.3)	1.1 (0.2)	35.9 (6.6)	50.2 (6.3)	13.9 (0.3)	Silt loam
Backslope	0	0	0.08 (0.1)	0.4 (0.6)	26.5 (4.2)	62.2 (4.2)	11.4 (0.01)	Silt loam
Field Edge	0	0	0	1.1 (1.5)	42.6 (25.5)	47.0 (23.6)	10.4 (1.9)	Loam
			10 to 20 cm					
			Beaver Crossing					
Road edge	4.5 (1.8)	1.9 (0.03)	4.3 (0.6)	5.8 (2.4)	24.8 (7.1	48.6 (10.5)	26.7 (3.3)	Loam
Shoulder	4.5 (6.4)	3.6 (5.1)	4.5 (6.4)	4.8 (6.7)	23.4 (1.6)	51.1 (6.2)	25.5 (4.6)	Loam
Side Slope	4.6 (0.4)	3.1 (2.2)	13.8 (1.6)	7.7 (0.1)	27.1 (9.0)	50.5 (11.5)	22.5 (2.5)	Silt loam
Ditch	1.7 (2.4)	1.6 (1.4)	6.3 (5.1)	5.2 (0.9)	28.0 (17.3)	47.0 (9.6)	31.1 (0.9)	Clay loam
Backslope	0	0	0	0	23.4 (9.1)	47.7 (9.3)	29.0 (0.2)	Clay loam
Field Edge	0	0	0	0	19.0 (7.8)	52.4 (8.1	28.6 (0.3)	Silty clay loam

				Sargent				
Road edge	21.3 (9.6)	3.4 (4.7)	20.1 (2.3)	5.6 (0.2)	67.1 (10.6)	23.8 (7.2)	9.1 (3.4)	Sandy loam
Shoulder	8.1 (1.3)	0.3 (0.3)	7.8 (4.6)	3.0 (0.5)	51.9 (15.3)	32.2 (12.6)	12.8 (1.6)	Loam
Side Slope	5.8 (0.04)	2.3 (0.6)	9.5 (1.1)	4.1 (2.0)	47.2 (5.5)	40.3 (3.9)	12.5 (1.6)	Loam
Ditch	0.3 (0.4)	0	1.1 (0.6)	1.5 (0.6)	37.1 (11.3)	45.3 (5.9)	17.7 (5.4)	Loam
Backslope	0	0	0.1 (0.1)	0.7 (1.0)	20.1 (9.3)	68.5 (5.9)	11.4 (3.4)	Silt loam
Field Edge	0	0	0	0.1 (0.1)	48.4 (30.2)	37.6 (30.5)	13.9 (0.2)	Loam