REMEDIATING SOIL FOR SUCCESSFUL VEGETATION ESTABLISHMENT ALONG NEBRASKA HIGHWAYS

FINAL REPORT

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16. Abstract

Vegetation along roadsides is important to prevent soil erosion, provide habitat, and filter water running off the road. Vegetation close to the pavement along highways in Nebraska does not readily establish and persist. It is thought that the sodium and bulk density are the driving factors behind the lack of vegetation. After a construction project the shoulder is seeded into the compacted soil, and during winter salts can accumulate in the soil because of deicing agents being used. The purpose of our study was to determine if the sodium and bulk density are the driving factors of the vegetation cover. We also looked at how shoulder type and time since seeding affected the soil and vegetation cover. The study was conducted by collecting soil samples and identifying vegetation cover from 53 sites in three different regions, the Panhandle, Southcentral and Southeast regions, in Nebraska, USA. The soil was analyzed for pH, electrical conductivity, sodium, chloride and bulk density. At each site vegetation was designated into one of four categories, bare ground (>70%), annual vegetation (>70%), perennial vegetation (>50%), and bare ground-annual vegetation mix (~50-50%). We found that sodium and bulk density had little effect on the establishment and persistence of vegetation. Shoulder type and time since seeding showed limited effect on the soil variables measured. We suggest that post seeding events and disturbances may be contributing to the lack of vegetation along highways.

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Summary

Vegetation along roadsides is important to prevent soil erosion, provide habitat, and filter water running off the road. Vegetation close to the pavement along highways in Nebraska does not readily establish and persist. It is thought that the sodium and bulk density are the driving factors behind the lack of vegetation. After a construction project the shoulder is seeded into the compacted soil, and during winter salts can accumulate in the soil because of deicing agents being used. The purpose of our study was to determine if the sodium and bulk density are the driving factors of the vegetation cover. We also looked at how shoulder type and time since seeding affected the soil and vegetation cover. The study was conducted by collecting soil samples and identifying vegetation cover from 53 sites in three different regions, the Panhandle, Southcentral and Southeast regions, in Nebraska, USA. The soil was analyzed for pH, electrical conductivity, sodium, chloride and bulk density. At each site vegetation was designated into one of four categories, bare ground (>70%), annual vegetation (>70%), perennial vegetation (>50%), and bare ground-annual vegetation mix (~50-50%). We found that sodium and bulk density had little effect on the establishment and persistence of vegetation. Shoulder type and time since seeding showed limited effect on the soil variables measured. We suggest that post seeding events and disturbances may be contributing to the lack of vegetation along highways.

Keywords: shoulder, roadsides, sodium, bulk density, deicer, vegetation cover

Chapter 1 Introduction and Background

The Nebraska Department of Transportation (NDOT) is responsible for maintaining 16,000 km of highways (NDOT 2016). When road construction projects that create bare soil on roadside shoulders are completed, the shoulders are seeded to a mixture of grasses to provide ground cover. Once seeded, roadsides are monitored until perennial vegetation cover is 70 percent of what was present before construction (Department of Environmental Quality, 2016). When the acceptable level of cover is not achieved, the shoulder may be seeded again, requiring greater demand on financial and human resources. Vegetation along the roadside is important for multiple reasons, including protecting against soil erosion, helping increase water infiltration into the soil, reducing runoff that carries pollutants, and providing habitat for insects, birds, and small mammals (Chen et al., 2019; Grace, 2002; Ries et al., 2001; Rothholz and Mandelik, 2013; Kaighan and Yu, 1996). Mixture of vegetation was also the preferred scenery on roadsides, compared to monocultures, bare ground or human made objects. (Akbar et al., 2003; Fathi and Masnavi, 2014).

1.1 Salinity and Sodicity

Roadsides can be unsuitable ground for vegetation establishment and persistence (Christen and Matlack, 2006; Godefroid and Koedam, 2004) because of deicing salt washing off the road, high soil compaction from road construction, vehicle traffic from cars pulling off roads, and drought-like microclimates resulting from heat reflected off the pavement (Forman, 2003). Saline soils are soils that are high in soluble salt concentrations, typically chlorides (Cl^-) or sulfates of sodium (Na), magnesium (Mg) and calcium (Ca) (Keller et al., 1986; Rengasamy and Walters, 1994; Seelig, 2000). Sodic soils are different from saline soils because they are high in only Na ions (Qadir et al., 2001). Saline and sodic soils on roadsides can develop from the use of deicing salts which are carried to road shoulder by snow melt and rain (Haan, 2012; Thompson et al., 1986; Rutter and Thompson, 1986). Roadway deicing salts, like sodium chloride (NaCl) and magnesium chloride (MgCl), can affect the germination of grasses and forbs (Dudley et al., 2014; Zhang et al., 2012). Green et al. (2008) found that NaCl used on the roads as a deicing agent affects the nitrogen (N) cycle in soil. When the Na is washed off the road it replaces the ammonium (a source of N) in the roadside soils on the cation exchange capacity (CEC); this decreases the space on the CEC where other nutrients can be held. Ke et al. (2013) found that when NaCl was added to the soil, negative changes to the electrical conductivity (EC), CEC, Na and Cl were strongly correlated with negative changes in microbial populations. Juniper and Abbot (2006) reported a similar reduction of fungal and bacteria population surrounding the plant rhizosphere when NaCl was added to the soil solution.

Saline or sodic conditions can negatively affect vegetation establishment in many ways. Plants grown in in saline conditions are water stressed due to increased osmotic potential, thereby reducing production (Rodriguez et al., 2005). It can also cause a reduction in chlorophyll content and/or an increase in secondary metabolite concentration in plants (Jaleel et al., 2008). Sodic soils can make vegetation establishment difficult by limiting nutrient availability (Naidu and Rengasamy, 1993). Sodium, when in high concentrations, can replace other nutrients, such as Ca, Mg and potassium (K) on the soil CEC sites. High Na concentration can limit root uptake of K, which limits plant enzyme activity and increases the abscisic acid production which in turn slows photosynthesis by closing stomata (Grieve et al 2012; Zhu 2007). But the main concern with sodic soil is that it can affect the soil physical properties of soil by dispersing soil aggregates and reducing soil water infiltration (So and Aylmore, 1993). Chloride, unlike Na, is a micronutrient for plants and is needed for growth, but in high concentrations, it is toxic to plants (White and Broadley, 2001). Chloride can inhibit the uptake of certain nutrients such as nitrate (Maas and Grattan, 1999) and increase osmotic stress (Grieve et al., 2012).

1.2 Compaction Issues

Other than salt issues on roadsides, compaction is common factor reported affecting vegetation establishment and persistence on roadsides. During construction of highways, roadbeds are compacted to provide a solid base for the highways (NDOT, 2017). The use of heavy machinery compacting soil causes unsuitable conditions for growth of vegetation and limit water infiltration (Berli et al., 2003). Horn et al. (1995) found that an increase in bulk density decreased pore space and slowed aeration and diffusion of water, ions, and gasses. Root growth and development is also impeded as bulk density of soil increases (Horn et al., 1995; Unger and Kasper, 1994; Sveistrup and Haraldsen, 1997). Skinner et al. (2009) found that root growth became more horizontal with high bulk density, leaving plants susceptible to water deficiency when the soil surface was dry. High bulk densities not only affect root growth, but also aboveground biomass production and tiller numbers (Houlbrooke et al., 1997). Grass emergence and seedling growth are reduced by high bulk density of the soil (Bartholomew and Williams, 2010; Barton et al., 1966).

1.3 Remediation Trials

1.3.1 Beaver Crossing Trial

Soil remediation trials were set up at Beaver Crossing, Nebraska in November of 2017. This trial was set up to see if it is possible to remediate soil and improve the quality of soil for improved vegetation establishment on highway shoulders. Treatments were as follows for the trial: 1. Control, no additives or disturbance was were added to the plot. 2. Mechanical disturbance, discing the soil to a 7.5 cm (3-inch) depth. 3. Mechanical disturbance with biotic earth sprayed on the plot. 4. Ripping the soil with biotic earth applied, the ripping was 10 cm (4-inch) deep trenches, 0.3 m (1 foot) apart. 5. Biotic earth was sprayed on with no disturbance. 6. Mechanical disturbance with gypsum added. 7. Mechanical disturbance with composted yard waste (LinGro). Seed was drilled into the plots and they were covered in hay mulch. During a visit to the sites in February 2018 we noticed over the winter months the plots were compromised by a snowplow. This led to the setting up plots at a different location.

1.3.2 Sargent Trial

Two sites in Sargent, Nebraska were set up in April of 2018, with each site having 5 blocks of 7 plots. Treatments were mostly the same as the Beaver Crossing sites except number 5 was changed to a ripping with gypsum added to the plot. Data were collected at these two sites throughout the summer. These plots were also compromised at the end of the summer in August of 2018, by mowing the plots. With both remediation experiments being compromised we needed to think of a way to accomplish our goals and to collect data from sites that would not be easily disturbed. We decided to conduct a survey throughout the state by collecting soil and vegetation data throughout in three regions of the State.

1.4 Objectives of Survey

There has been research conducted on roadsides in different parts of the country addressing the objective of establishing perennial vegetation on the harsh roadside environments. The objective of our study was to identify why some roadside shoulders lack vegetation. The effect that time since seeding and shoulder type (paved vs unpaved) had on soil properties at two depths in Southeast, Southcentral and the Panhandle of Nebraska were assessed. We hypothesized that salt and compaction issues of soil were the main factors causing the lack of vegetation. We also hypothesized that paved shoulders provided better environment, less Na and lower bulk density, than unpaved shoulders; and that older projects would have higher Na levels than newer projects.

Chapter 2 Materials and Methods

2.1 Study Locations

Soil samples were collected in three regions in the state of Nebraska. The three regions were the Southeastern part of the state, the Southcentral region, and the Panhandle as defined by the Nebraska Department of Transportation (NDOT) Landscape Regions map (NDOT, 2019; **Figure 2.1**).

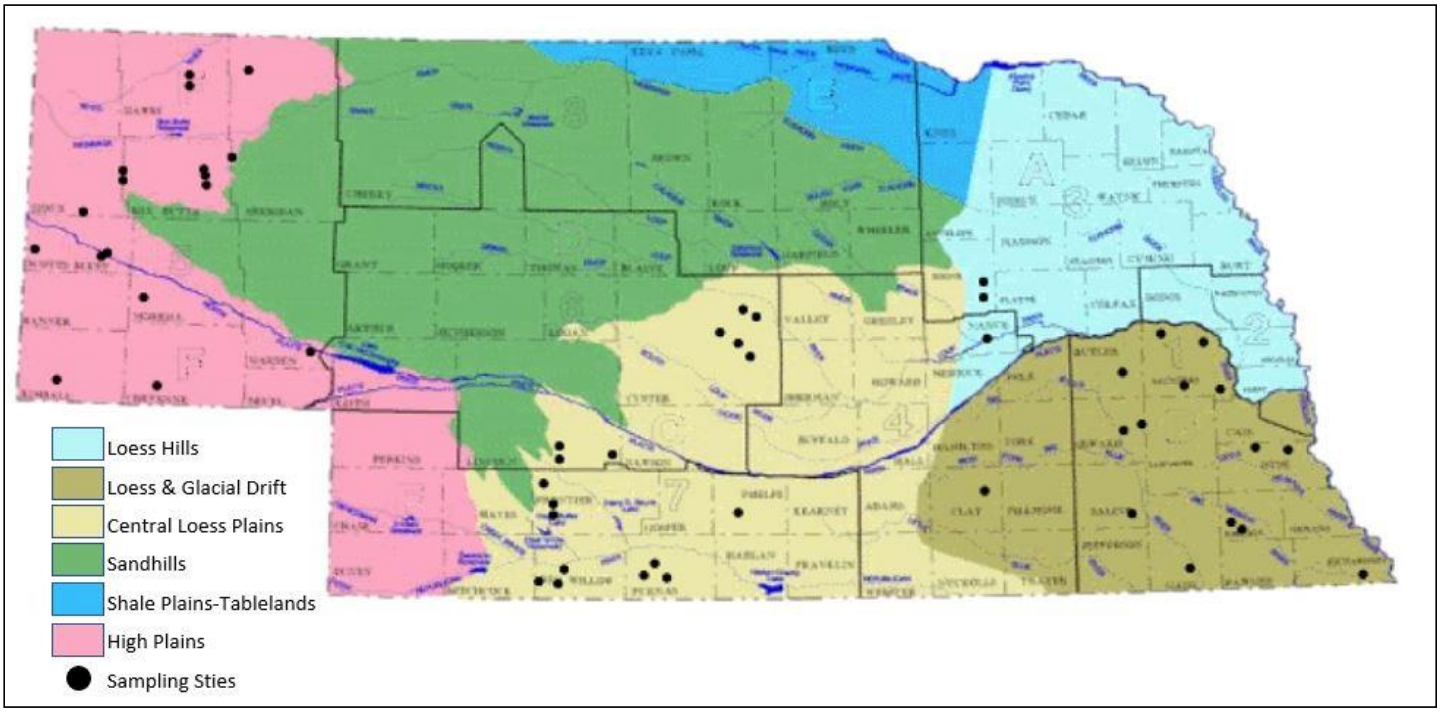


Figure 2.1 Sampling locations within each sampled region; Panhandle comprised of High Plains, Southcentral comprised of Central Loess Plains and Southeast comprised of the Loess Hills and Loess & Glacial drift.

2.1.1 Southeastern Region

The Southeastern region is in the loess and glacial drift ecoregion. The climate is a hot summer humid continental climate (Köppen, 1936) with an average high of 17.3° C (63.1° F) and average low of 4.4° C (39.9° F). The average annual precipitation for the Southeast is 735 mm (28.9 in) with 73% as rainfall during the growing season (April through September).

According to the Nebraska Soil Association Map (Elder, 1969), the five prevalent soil associations include Hastings (Fine, smectitic, mesic Udic Argisustoll)-Crete (Fine, smectitic, mesic Pachic Udertic Argiustoll), Aksarben (Fine, smectitic, mesic Typic Argiusdoll)-Marshall (Fine-silty, mixed, superactive, mesic Typic Hapludoll), Wymore (Fine, smectitic, mesic Aquertic Argiudoll)-Pawnee (Fine, smectitic, mesic Oxyaquic Argiudoll), Crete-Wymore, and Crete-Fillmore (Fine, smectitic, mesic Vertic Argialboll). The native vegetation cover of this region is tallgrass prairie dominated by warm-season, tall grasses including big bluestem (*Andropogon gerardii)*, indiangrass *(Sorghastrum nutans),* and switchgrass *(Panicum virgatum*). The roadside shoulders were seeded to a mixture of perennial ryegrass (*Lolium perenne)*, western wheatgrass (*Pascopyrum smithii),* slender wheatgrass *(Elymus trachycaulus),* tall fescue *(Festuca arundinacea),* red fescue *(Festuca rubra),* blue grama *(Bouteloua gracilis),* sideoats grama *(Bouteloua curtipendula),* buffalograss *(Bouteloua dactyloides),* and sand dropseed *(Sporobolus cryptandrus).*

2.1.2 Southcentral Region

The Southcentral region is in the central loess plains ecoregion and covers the central portion south of the Sandhills. The climate is a hot summer, humid continental to humid subtropical (Köppen, 1936) with an average high temperature of 16.5° C (61.5° F) and an average low of 1.7° C (35.1° F). The average annual precipitation for the Southcentral is 528 mm (20.8 in) with 77% as rainfall during the growing season. The three prevalent soil associations (Elder, 1969) include Holdrege (Fine-silty, mixed, superactive, mesic Typic Argiustoll)-Colby (Fine-silty, mixed, superactive, calcareous, mesic Aridic Ustorthent), Holdrege-Hastings, and Colby-Ulysses (Fine-silty, mixed, superactive, mesic Torriorthentic Haplustoll). The Southcentral region is broadly considered Mixed Prairie dominated by a mixture of tall and short grasses. The shoulder seeding mixture in this region was the same as that of the Southeastern region plus sand lovegrass *(Eragrostis trichodes).*

2.1.3 Panhandle Region

The Panhandle is in the high plains ecoregion of western Nebraska. The climate is classified as cold and semi-arid (Köppen, 1936) with an average high temperature of 17.5°C (63.5° F) and an average low of 1.1° C (34.0° F). The average annual precipitation for the Panhandle is 400 mm (15.7 in) with 73% as rainfall during the growing season. The three prevalent associations (Elder, 1969) were Keith (Fine-silty, mixed, superactive, mesic Aridic Argiustoll)-Rosebud (Fine-loamy, mixed, superactive, mesic Calcidic Argiustoll), Anselmo (Coarse-loamy, mixed, superactive, mesic Typic Haplustoll)-Keith, and Mitchell (Coarse-silty, mixed, superactive, calcareous, mesic Ustic Torriorthent)-Tripp (Coarse-silty, mixed, superactive, mesic Aridic Haplustoll). The native vegetation cover of this region is Shortgrass Prairie dominated by buffalograss, blue grama, and western wheatgrass. The seeding mixture used on shoulders of Panhandle study sites was the same as that of the southeastern region plus thickspike wheatgrass (*Elymus lanceolatus)* and little bluestem (*Schizachyrium scoparium).*

2.2 Study Design

Highway shoulders varied by sites, paved shoulders varied from 1.8 to 2.4 m (6 to 8 ft) of pavement next to the highway lane with unpaved shoulders having 0.3 m (1 ft) or less of pavement next to the highway lane. During the construction process soil is compacted to provide a stable foundation for the pavement. The shoulder is the level area that is paved or unpaved directly next to the road and sits above the front slope and ditch (**Figure 2.2**). The compaction of the road can extend past the pavement when the shoulder is not paved. After the construction is completed, the seed is drilled into the compacted soil. A project is completed once the vegetation cover is at 70% of that of the pre-construction. If vegetation is not established, reseeding of the shoulder may occur. Mowing and noxious weed removal are the only management activities performed after vegetation is established on the shoulder.

Study sites within each region were identified in 2018 with the assistance of employees from NDOT (**Appendix Table 1**). Each site, a chosen roadway/highway construction project, was categorized according to time since seeding (0-1 year, 2-4 years and 5+ years), and the shoulder type (unpaved or paved). To ensure adequate sampling, three project sites from each project year category within each region were randomly selected for soil sampling (3 sites x 3 project age x 2 shoulder types = 18 sites per region). Eighteen sites were identified and sampled for the southcentral and southeastern regions; however, only two project sites fit the unpaved, the 0-1 year category for the Panhandle region, resulting 17 sites (**Figure 2.1**).

Soil samples were collected from three locations along the highway at a 3 km (2 mi) interval. Samples were collected from each site using a JMC Backsaver (Clements Associates, Inc.) soil probe, during May of 2019. Two depth intervals 0-10 cm (0-4 in) and 10-20 cm (4-8 in) were collected in plastic sleeves put in the soil probe to yield a total of 54 samples per region. Samples were taken from level stretches on the west side or south sides of the road so that topography would have little bias on sampling. To limit bias from traffic, samples were taken 60 m from any road intersections, bridges or any sort of entrances such as to a field or homestead. Samples were kept in a cooler with ice while in the field and put in a freezer, at -10° C (14° F), until lab analyses. Samples were thawed 24 hours before analysis.

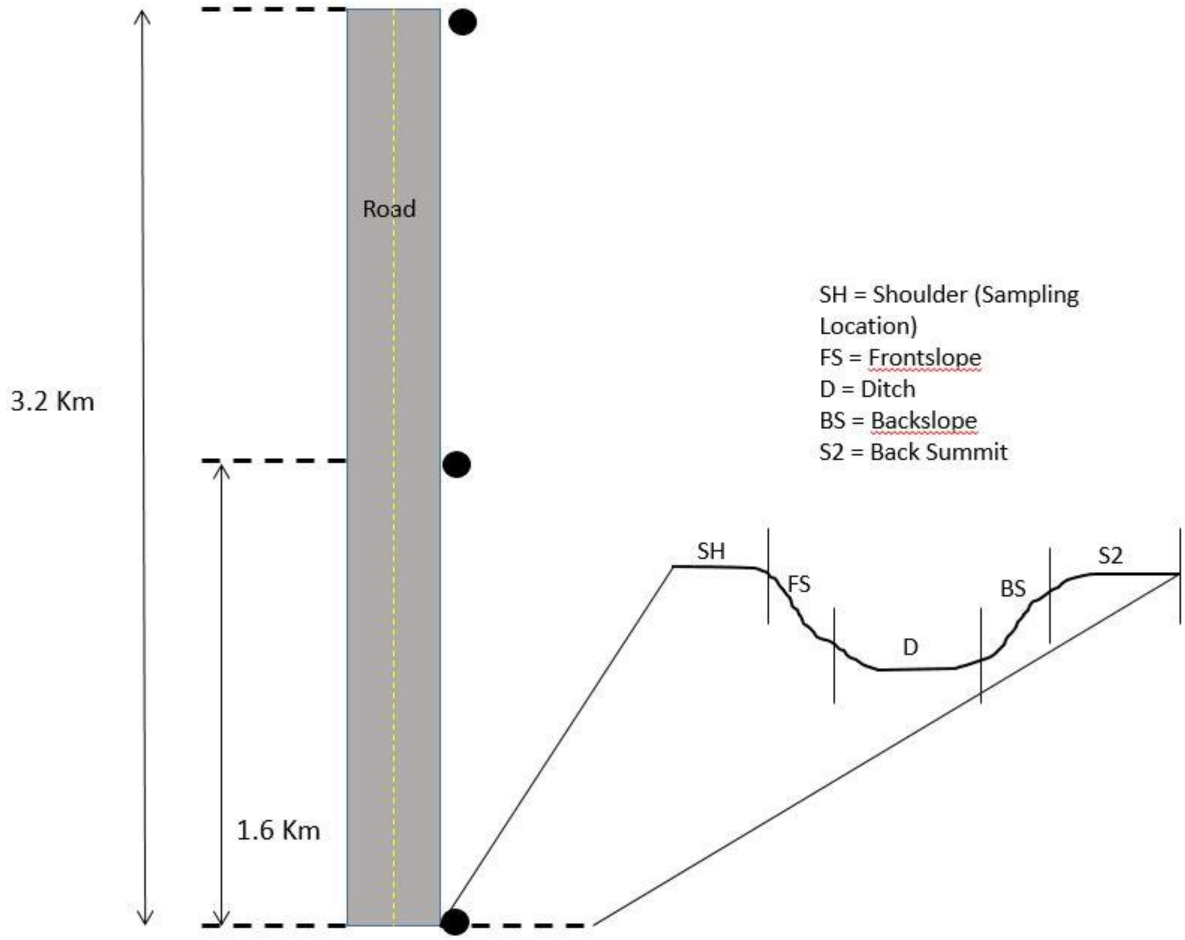


Figure 2.2 Sampling was done in the shoulder position, 30 cm (1 ft) off the pavement. Three samples were collected in a 3.2 km (2 mi) stretch of highway and were 1.6 km (1 mi) apart.

2.3 Measuring Soil Properties

Cores were split into 0-10 cm (0-4 in), and 10-20 cm (4-8 in) increments, and initial weight was recorded. Soil at each depth was oven dried at 105° C (221° F) for 24 hours, and the dry weight was recorded. The bulk density was determined from the ratio of oven dried soil weight to soil volume at the corresponding depth. To remove gravel-sized particles, samples from each site were crushed to break any soil aggregate and sieved through a 2-mm mesh sieve.

Soil samples were then re-weighed and divided the initial dry weight to obtain gravel content by percent weight.

Soil samples were analyzed for texture, pH, EC, Na, Cl, Ca, Mg, and K. Soil pH was measured at a 1:1 soil/water ratio, soil EC was obtained by saturated paste extract, and cations (Ca, Mg, K, and Na) by ammonium acetate extraction method (Nelson and Sommers, 1996; Sumner and Miller, 1996). The soil CEC was determined by summation of the measured cations. Soil texture was determined using soil particle distribution of the samples (Arriaga et al., 2006). This was done using a laser diffraction machine produced by Malvern Panalytical, particle size distribution was graphed for each sample. Using standard USDA particle size classification (Soil Science Division Staff, 2017) percent clay and silt were determined from the distribution.

2.4 Categorization of Vegetation Cover

Vegetation cover along roadsides can be variable throughout the state. NDOT wanted to know why the cover of the seeded perennial grasses was so variable and if the compaction of the soil and salts applied as winter treatment were limiting factors. The cover was evaluated at the time of soil sampling in early May through observation at each site; looking at the first meter (3 feet) of soil from the pavement. We determined four categories to be used in the evaluation; (1) bare ground, which is greater than 70%; (2) site was dominated (greater than 50%) by perennial grass cover. We had two intermediate categories, (2) when plant cover was greater than 70% by weedy annual grasses and forbs, and (4) when there was a 50-50% mix of bare ground and annual vegetation. These categories were used to determine if soil variables had any influence on the type of cover present at each site.

2.5 Data Analyses

Analysis was performed using SAS 9.4 statistical software (SAS Institute, 2012). The mixed model type 1 analysis (Proc Mixed) was used where region, shoulder and age were fixed effects, but site nested within region was a random effect. Principal component analysis (Proc Princomp, SAS 9.4) was used to determine whether any soil variables or combination of variables influenced the vegetation category.

Chapter 3 Results and Discussion

3.1 Chemical Properties

3.1.1 Sodium

Sodium concentration in the soil varied significantly by region at both depth intervals (**Figure 3.1a**) For the 0-10 cm (0-4 in) depth, the Panhandle region had one-third to one-half the amount of Na (480 ppm) than the Southcentral and Southeastern regions (986 and 1413 ppm, respectively). At the 10-20 cm (4-8 in) depth, soil Na concentration in the Panhandle region was two to three times lower (520 ppm) than in the Southcentral and Southeastern regions (1034 and 1818 ppm respectively). We expected that the Panhandle region would have lower soil Na content because of sandier textures, we found no correlation between the percentage sand and the Na concentrations in soil samples collected (**Appendix 1**). We also hypothesized that high clay percentages with increased CEC in the soil might increase the soil's retention of Na and minimize leaching; however, there was also little correlation between clay percentage and Na concentration in soils of roadside shoulders (**Appendix 2**). This lack of correlation could mean that there was adequate precipitation to move ions out of the sampling depths in the soil.

In Nebraska, NaCl is the most commonly used deicer, but MgCl and sand are also used on occasion (NDOT, personal communication). Sodium chloride can be moved off the shoulder area where we sampled. Sodium chloride applied to highways dissolves during precipitation events and may run off highway shoulder surfaces into ditches before infiltrating the soil. Snow on the highways and shoulders may also be pushed away by snowplows into ditches, thereby moving Na away from the shoulder area we sampled.

Regional differences in Na concentration can be attributed to the amount of days the NaCl is applied. Application of the NaCl during winter months is dependent upon freezing temperatures and the frequency and amount of precipitation in the region. Over the last five years, the Panhandle region had an annual average of 27 days with an average high temperature under 0° C (32° F) from November to March, with the Southcentral and Southeastern regions having 41 and 34 days, respectively. The product used in the Southeastern region is a brine (NaCl and water) solution, while rock salt is more commonly used in the Panhandle region (NDOT, personal communication). The brine solution has a lower concentration of Na, typically one quarter to one fifth (typically 23.3% NaCl to 76.7% water) as much Na as rock salt (American Public Works Association, 2016); however, the frequency and amount of deicer material applied is not recorded/known by region. The application rate of brine in the Southeastern region could far exceed that of rock salt in the Panhandle. To further study the effect of deicer on soil salinity, the amount and frequency of deicer application on highways needs to be quantified.

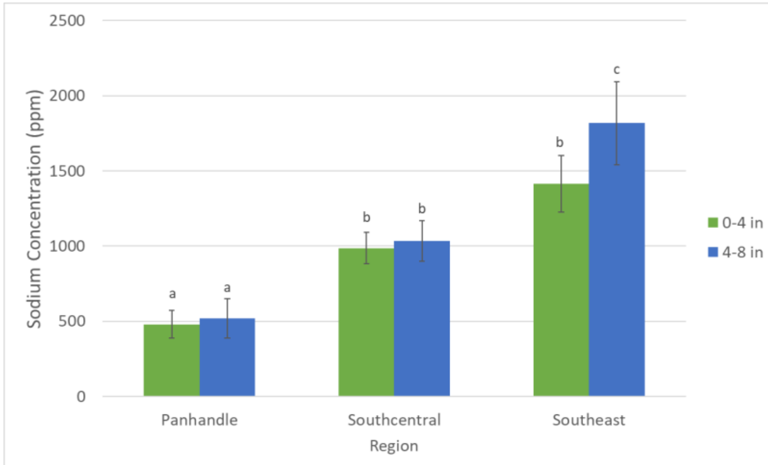
At both depths, soil Na concentration also differed between shoulder types (**Figure 3.1b**) but not by years. The soil Na concentration for the unpaved shoulder (1137 ppm) was about 50% greater than for the paved shoulders (782 ppm) for the 0-10 cm (0-4 in) depth. For 10-20 cm (4-8 in) depth the Na concentration of the unpaved shoulders (1410 ppm) was nearly 75% greater than that of the paved shoulders (838 ppm).

Highways with unpaved shoulders had a greater concentration of Na in the soil than paved shoulders (**Figure 3.1b**). It is possible that the paved shoulder provides a buffer between the highway surface where the deicer is applied and the soil bordering the pavement. The paved shoulder provides an extra 2.4 m (8 ft) of roadway where the water carrying salts can evaporate from the shoulder and deposit less salt in the adjacent soil.

There was a year (**Figure 3.1c**) effect at the 10-20 cm (4-8 in) depth. At this depth the soil Na concentration for the 0-1 year-old-sites (827 ppm) was less than the 2-4 year and 5+ year-old-sites (1225 and 1319 ppm, respectively). The year effect for Na concentrations, could be due to accumulation of Na overtime. If new soil is brought in for a project Na concentration could be low.

Exchangeable sodium percent (ESP), the fraction of Na present relative to the CEC in the soil, is used to determine the effect Na may have on the soil varied by region as well. The Panhandle region average ESP was 10.3% which was half that of the Southcentral and Southeast regions (23.4 and 27.1% respectively) for the depth of 0-10 cm (0-4 in). For the depth 10-20 cm 4-8 in), it showed a similar pattern, with the Panhandle region (9.5%) being almost a third of that of the Southeast (28.3%) and the Southcentral (24.6%) regions.

The ESP level for optimal soil conditions is typically less than 15% (Zaman et al., 2018). The ESP, EC, and pH can be used to determine the soil salinity conditions (**Figure 3.2**). Based on ESP, EC, and pH, the roadside soils at the Panhandle region were within the normal soil category according to the NRCS, below the 15% threshold, but still high for a normal Nebraska soil, while the Southcentral and Southeastern regions were slightly in the sodic category. There were 29 sites at both depths in the sodic category (**Table 3.1**). The main concerns with a sodic soil are problems with soil physical properties. Sodium is a dispersing agent and when it is in high concentrations on the CEC sites can degrade the physical structure of the soil. The structure of the soil at our sampling sites were not tested for structure integrity but no sites appeared to have structural issues a)



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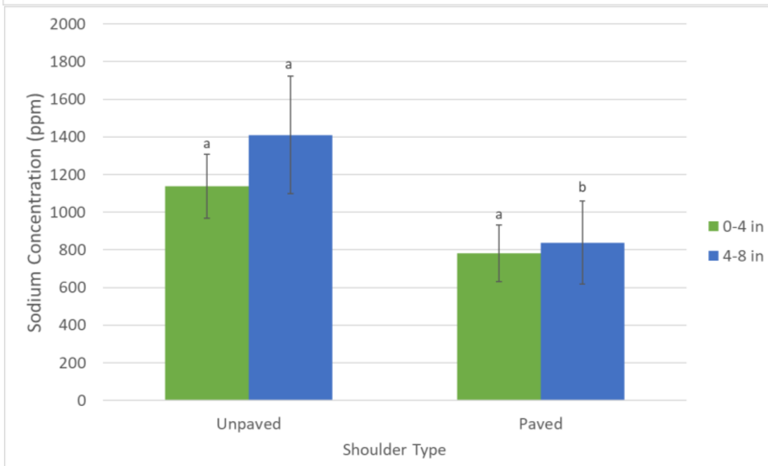

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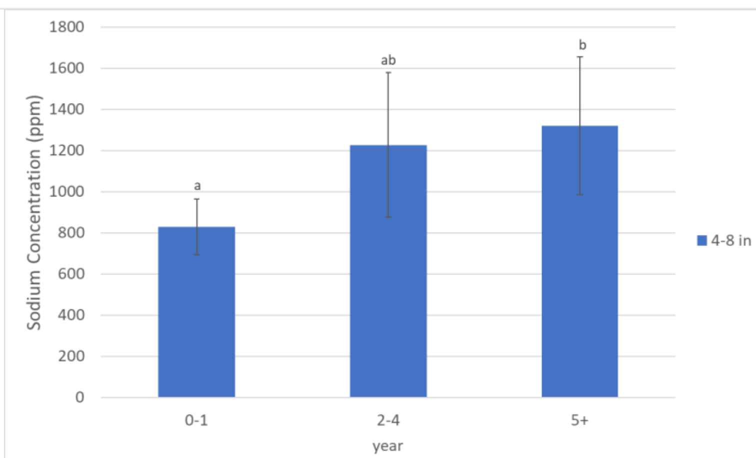

Figure 3.1 Differences of sodium concentrations by region, shoulder type and year. (a) Shows the difference in concentration levels by region with the Panhandle region having the lower concentrations at both depth intervals. (b) Shows the difference by shoulder type with unpaved shoulders having higher concentrations at both depth intervals. (c) Shows the difference by year for only 10-20 cm (4-8 in) depth, with 0-1 year having a lower concentration.

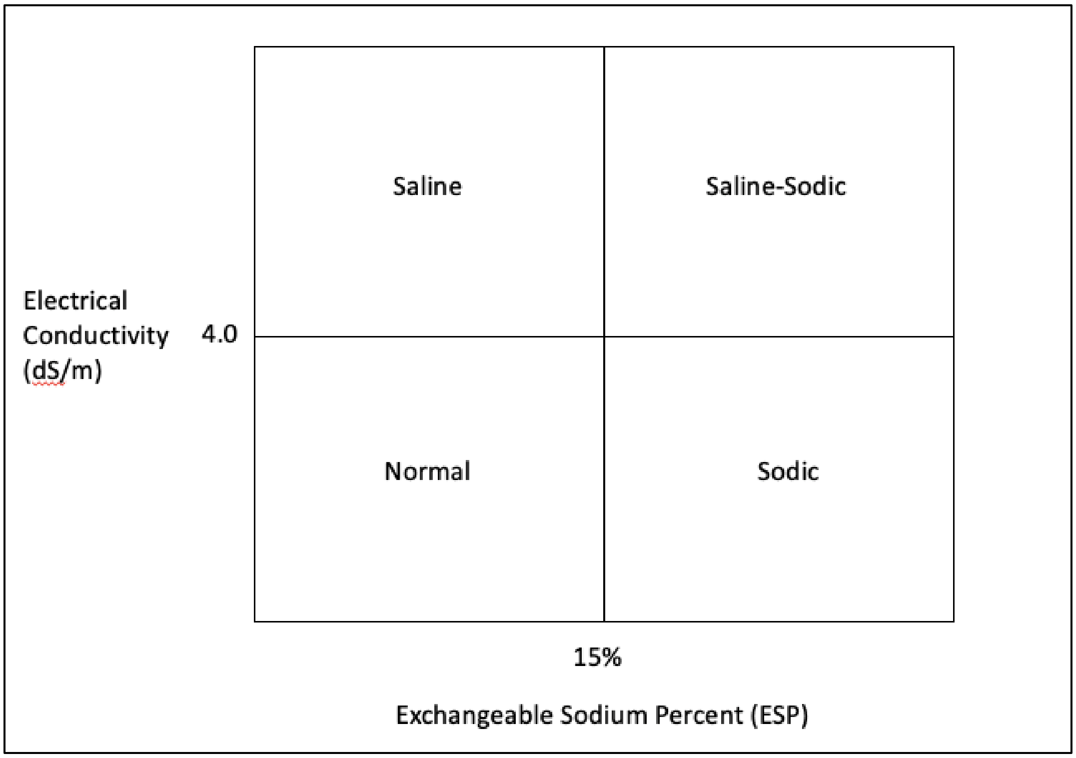

Figure 3.2 Shows the soil categories of saline and sodic with the respected variable used for determining classification.

Table 3.1 The percent of the total sites for each soil category based on EC, ESP and pH.

Soil Category	Depth (cm)	# of Sites	Percent of Sites
Normal	0-10	24	45.3%
Sodic	0-10	29	54.7%
Normal	10-20	23	43.4%
Sodic	10-20	29	54.7%
Saline-Sodic	10-20	1	1.9%

3.1.2 Chloride

Chloride had a regional effect and showed a west to east gradient (**Figure 3.3**). The Panhandle region was 2.5 to almost five times lower than the other two regions at both depths (150 and 187 ppm, for 0-10 cm (0-4 in) and 10-20 cm (4-8 in) respectively). The Southcentral region had concentrations of 384 and 488 ppm for 0-10 cm (0-4 in) and 10-20 cm (4-8 in) respectively, while the Southeast region had 734 and 995 ppm for 0-10 cm (0-4 in) and 10-20 cm (4-8 in), respectively. The Cl^- concentration showed a similar east to west gradient with lower concentrations in the Panhandle region and higher concentrations in the Southeastern region. Due to the negative charge of Cl^- ions they are not held on CEC sites and are more readily carried by water out of the root zone. Sandier-textured-soils also have lower CEC and cannot hold on to as many ions as a texture with higher CEC like silt or clay soils (Ketterings et al., 2007).

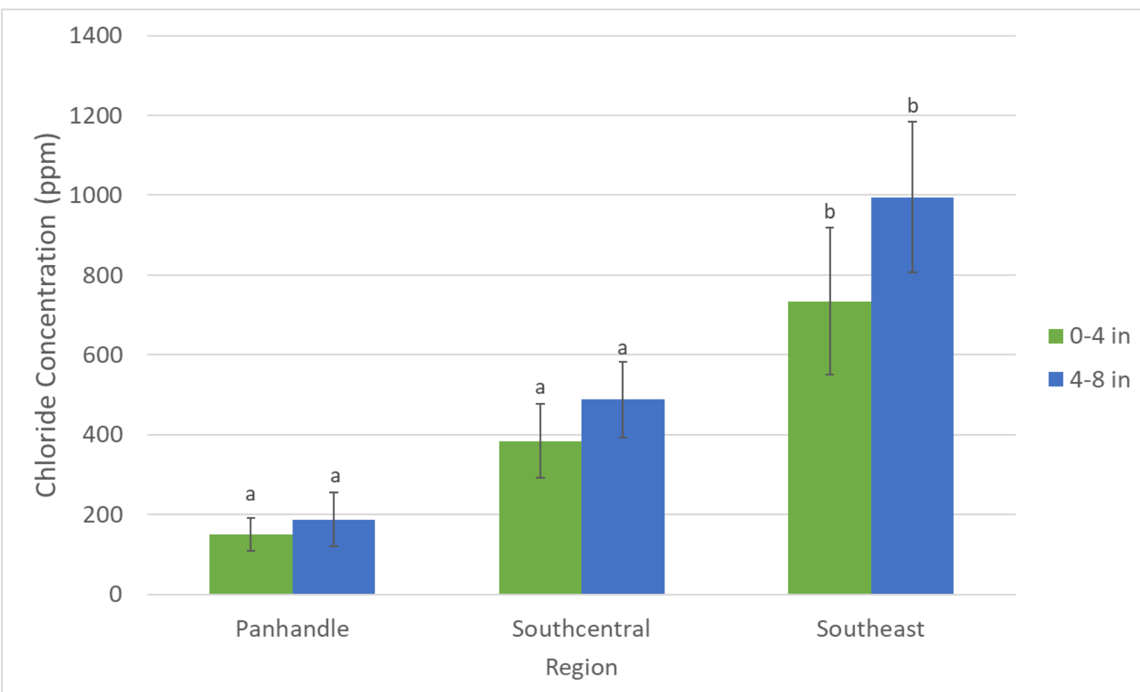

Figure 3.3 Chloride concentration differences by region. Showed a similar west to east gradient, with Southeast region being the highest concentration

3.1.3 Electrical Conductivity

Electrical conductivity at both depths differed by region (**Figure 3.4a**). The EC in the Panhandle region (0.11 mmhos/cm) was two to 3.5 times less compared to the Southcentral and Southeastern regions (0.28 and 0.39 mmhos/cm, respectively). From 10-20 cm (4-8 in) depth EC of soils from 10-20 cm (4-8 in) in the Southeastern region (2.07 mmhos/cm) was about two times greater than that from the Panhandle and Southcentral regions (0.87 and 1.09 mmhos/cm, respectively). Differences although significant, were still within a normal range found on perennial grasslands (NRCS, 2014). The EC threshold above which aboveground production of such grasses as tall fescue (*Festuca arudinacea)* and crested wheatgrass (*Agropyrum cristatum)* is reduced is 2.8 and 2.5 mmhos/cm, respectively (NRCS, 2014). The EC of the soils we collected were below these values given in the guide. The lower EC value measured in the Panhandle region could be due to increased macropore space from its sandier texture allowing water to carry salt below the rootzone and reducing Na and other salt concentrations in the 0-10 cm (0-4 in) soil depth. This can be seen as EC was greater for the 10-20 cm (4-8 in) depth than the 0-10 cm (0-4 in) depth. Amount of deicer salts applied could also influence the EC values as it does the Na concentration. Electrical conductivity measures would be influenced not only by Na ions but Cl^- ions as well; the Cl^- would be present in the soils at higher levels which would increase EC values (NRCS, 2014) if high application rates were applied.

Shoulder type (**Figure 3.4b**) affected EC at both depths, for 0-10 cm (0-4 in) the paved shoulder (0.21 mmhos/cm) was one-third less than it was for the soil from an unpaved shoulder (0.30 mmhos/cm). For the depth of 10-20 cm (4-8 in) (**Figure 3.4b**), the EC on the paved shoulder (0.97 mmhos/cm) was about half that of the unpaved shoulder (1.72 mmhos/cm). The reasons for EC differences by shoulder type in the soil was likely similar to that of Na concentration differences. Sodium and Cl^- ions form salt as water evaporates on the highway (Guglielmini, 2008). Having a paved shoulder allows for greater area, a buffer, to collect all ions after evaporation of water in which ions are dissolved. If the salts are present on the pavement after evaporation they may be carried by future precipitation or wind. The shoulder type difference may be due to where snow is piled as it is plowed. As snow is removed from the highway, it is plowed onto the shoulder. As temperatures increase, snow will melt on the paved shoulder leaving salts on the pavement; but with an unpaved shoulder the snow will sit directly on the soil while it melts carrying any salts into the soil.

a) b)

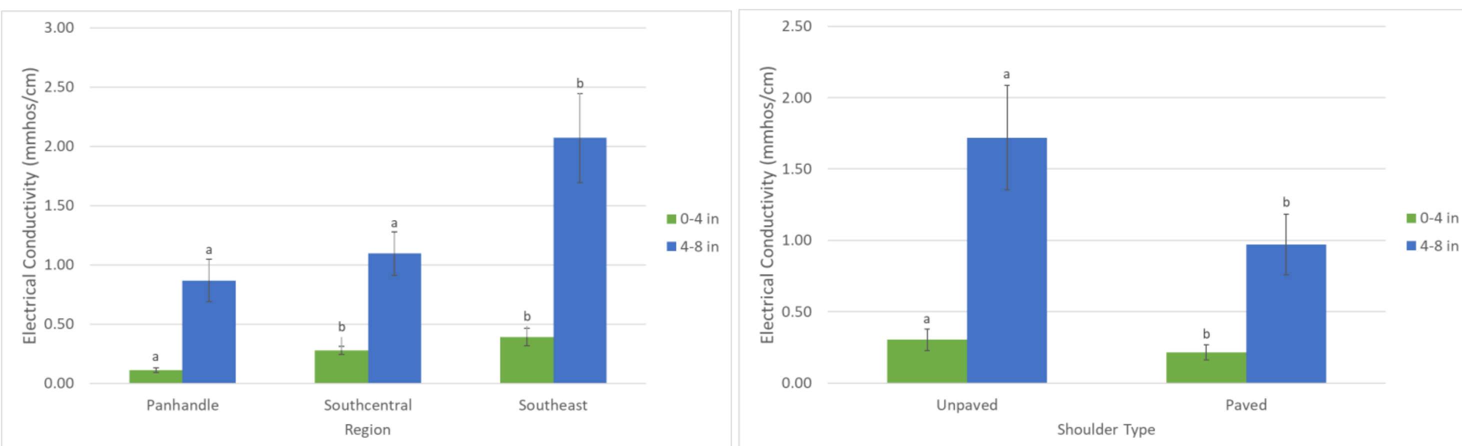

Figure 3.4 Differences of electrical conductivity (EC) by region and shoulder type. (a) Shows the differences by region with an increase from west to east. (b) Shows the difference by shoulder type with unpaved shoulders having higher values at both depth intervals.

3.1.4 pH

At the 10-20 cm (4-8 in) depth, pH was found to be significant only by region (**Figure 3.5**). The pH of Panhandle soils (9.07) was greater than the Southcentral and Southeastern regions (8.83 and 8.78, respectively). The interaction of year x shoulder x region was significant for the 0-10 cm interval (Fig. 7). The soil pH for the 2-4 year category of both paved and unpaved in all regions was greater than the 0-1 year and 5+ year categories, except for at sites with paved shoulders in the Panhandle region where the 2-4 year category was the minimum (8.60). The 0-1 year category and the 5+ year category seemed to be consistent with each other over both shoulder types in all three regions; except for sites with unpaved shoulders in the Southcentral region where the 0-1 year category was the minimum average (8.27) and the 5+ year category was the maximum average (9.33).

The soil pH in the Panhandle region was significantly higher than the other two regions (**Figure 3.5**). Panhandle soils are naturally more basic than soils in Southcentral and Southeastern Nebraska. The arid to semi-arid environment and naturally occurring bicarbonates have resulted in high soil pH in the Panhandle (Wang et al. 2009). The pH range for the region was slightly higher than expected. There was also a significant interaction of region x time since seeding x shoulder for pH at the 0-10 cm (0-4 in) soil depth (**Figure 3.6**). This interaction could be due to differences in construction processes by region and over time. There are several methods by which soil is placed next to the highway pavement, including replacing topsoil that was removed, shaping the shoulder from a mixture of subsoil and topsoil, or having soil brought from another location (NDOT, personal communication).

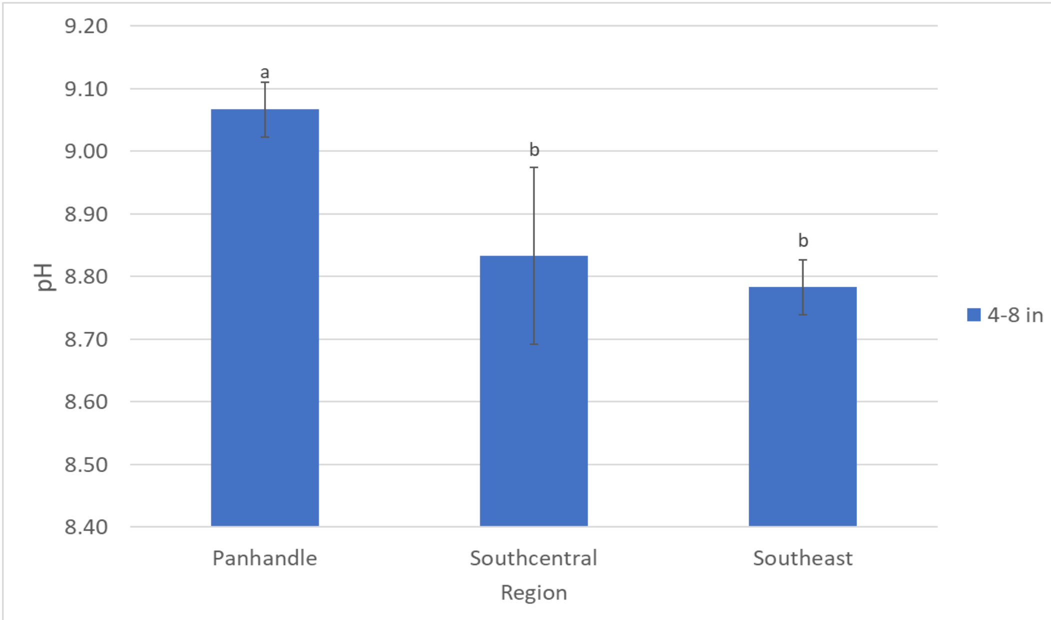

Figure 3.5 Regional differences of the pH at 10-20 cm (4-8 in) depth, with Panhandle having a higher pH compared to Southcentral and Southeast

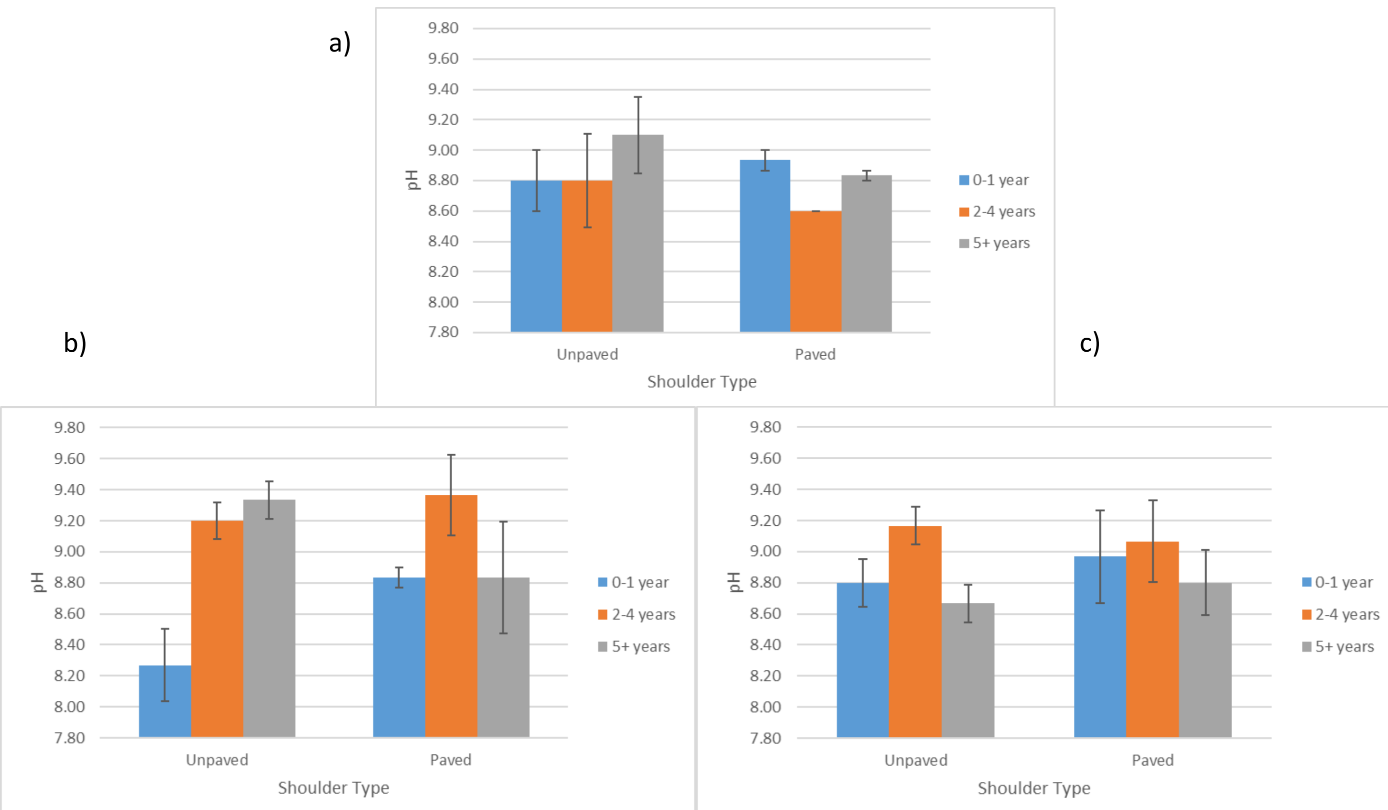

Figure 3.6 The year x shoulder x region interaction. (a top) Shows the interaction within the Panhandle region. (b left) Shows the interaction within the Southcentral region. (c right) Shows the interaction within the Southeast region

3.2 Physical Properties

Bulk density averaged 1.4 g cm^{-3} and 1.5 g cm^{-3} across all sites for soil depths of 0-10 (0-4 in) and 10-20 cm (4-8 in), respectively. Gravel content averaged 16.4% and 10% across all sites for soil depths of 0-10 (0-4 in) and 10-20 cm (4-8 in), respectively. Neither bulk density nor gravel content was affected by the main effects and there were no significant interactions. As expected, texture varied by region, in the Southeast averaged across sampling location, the soil texture was 27.7% sand and 14.6% clay. The Southcentral region was variable in texture, sandy loam to silt loam, with a minimum sand percent of 18.3 and a maximum of 75.1%. There was a maximum clay percent of 16.9 and a minimum of 4.7%. The Panhandle region had an average of 57% sand and 10% clay.

We had hypothesized that shoulder type would affect soil bulk density, with a relatively high bulk density for unpaved shoulders. We assumed the width of a compacted roadbed would be the same regardless of whether the shoulder was paved or not paved, resulting in the entire width of the highly compacted roadbed being covered by the highway lanes and the paved shoulder; whereas, the unpaved shoulder would leave part of the compacted roadbed exposed. However, the bulk density of the soil within 1 m (3 ft) of pavement edge did not differ between paved and unpaved shoulders. Time since seeding also had no effect on bulk density; however, we hypothesized that we would see differences.

In the Panhandle region the bulk densities ranged from 1.33 to 1.46 g cm^{-3}, respectively. With the sandy loam textures in the Panhandle region these bulk density values would be considered normal to slightly high but not root limiting (NRCS, 2019). The Southcentral region had a range of bulk densities from 1.42 to 1.51 g cm^{-3}, respectively. With a range of textures from sandy loam to silt loam, the bulk density values would be considered slightly high but not root limiting (NRCS, 2019). The Southeastern region had a range of bulk densities from 1.38 to 1.45 g cm^{-3}, respectively. These values would be considered slightly high but not root limiting (NRCS, 2019). Because none of the values would be root limiting, we would expect that bulk density would not affect the vegetation cover at any of the sites.

A reason for the high bulk densities could be due to traffic driving with wheels off the pavement and on the soil, especially on rural highways during planting and harvesting season, increasing the bulk densities at all locations (Raper, 2005). Tire tracks left from traffic were observed at almost all locations. Construction on roads involves high compaction of soils to provide stability for the pavement. The process of constructing and repaving roads may be similar throughout all regions. This could be the reason for the small range of values and similarity of values by region.

Percentage gravel in roadside soils was not affected by main effects or their interactions. The gravel was variable throughout all sites sampled; this could be because the pavement at the highway's edges breaks down and forms gravel-sized particles that end up in the soil. This was observed frequently in texture analysis of roadside soil sample. The origin of the roadside soils as noted earlier is not known for the projects and gravel also could have been present in soils before being placed on roadsides.

3.3 Vegetation Cover

The categorization showed that 50% of the 53 sites sampled had perennial vegetation established (**Table 3.2**). The principal components analysis (PCA) showed that no soil variable measured or combination of measured variables explained the type of vegetation cover found at the sampled sites (**Figure 3.7**). The PCA shows that there were no tight groupings of any of the vegetation types, nullifying our hypothesis that vegetation type was driven by sodium and bulk density.

Category of vegetation cover on the shoulders did not correspond to any measured soil variable or combination. Highway shoulders are not ideal environments for seeded perennial grasses to establish and persist. As discussed, some of the values measured like bulk density were high in the Southeastern region for the soil textures found, and Na concentration and exchangeable sodium rates were high in the Southeastern and Southcentral regions. They may not directly impact the vegetation found at the sampled sites, but they still contribute to a less than ideal environment. Once the vegetation is seeded on the roadsides there are many factors that can influence the growth and production in the first 2 m (6.5 ft) of soil from the pavement, whether or not there is a paved shoulder. Vehicles frequently pulling onto the shoulder can destroy vegetation by physically damaging the plant and decreasing cover of the soil (Kutiel et al., 2000; Rickard et al., 1994). It can also create ruts in the soil (Ayers, 1994) which can move soil and displace or destroy vegetation. In high snow drift areas, snow has to be removed from the soil areas of the shoulder (NDOT, personal communication) which can remove soil and vegetation with the snow, as we saw at a site near Beaver Crossing, Nebraska. Vegetation on shoulders is mowed to 15-cm heights, or less, frequently through the growing season on Nebraska highways (NDOT, 2019). The removal of leaf material of herbaceous plants (grasses and forbs) can negatively affect photosynthesis and carbohydrate storage for the subsequent year’s production and may lead to a decrease in vegetation cover. However, highway shoulder vegetation must be mowed regularly for safety reasons.

Lack of vegetation may also be due to seed viability of purchased seed. If seed purchased for a project has low germination rate, then a whole project planting may be compromised.

However, NDOT's seed approval process, combined with the use of PLS (pure live seed) calculations, ensures that the seed purchased for highway projects meets NDOT's specifications for seed performance. In an unpublished study we saw germination rates below 25% for a batch of seed labeled with 95% viable seed (Mills, unpublished data). Regions of Nebraska vary by natural vegetation type, with the Southeast region being in the tallgrass prairie, the Southcentral region in the mixed grass prairie and the Panhandle being in the shortgrass prairie. The prairie regions are consistent with a precipitation gradient, with higher annual precipitation in the east and lower annual precipitation in the west. Seeding mixtures used on shoulders throughout the state were fairly consistent as to the species being planted. More mixtures of grasses should be used that represent the ecosystem into which they are being planted. This could lead to higher successful vegetation establishment along highways (Petersen et al., 2004).

Table 3.2 The percent of the total sites for each vegetation category.

Vegetation Type	# of Sites	Percent of Sites
Bare Ground	10	18.9%
Annual Vegetation	3	5.7%
Perennial Vegetation	27	50.9%
Bare Ground/Annual Mix	13	24.5%

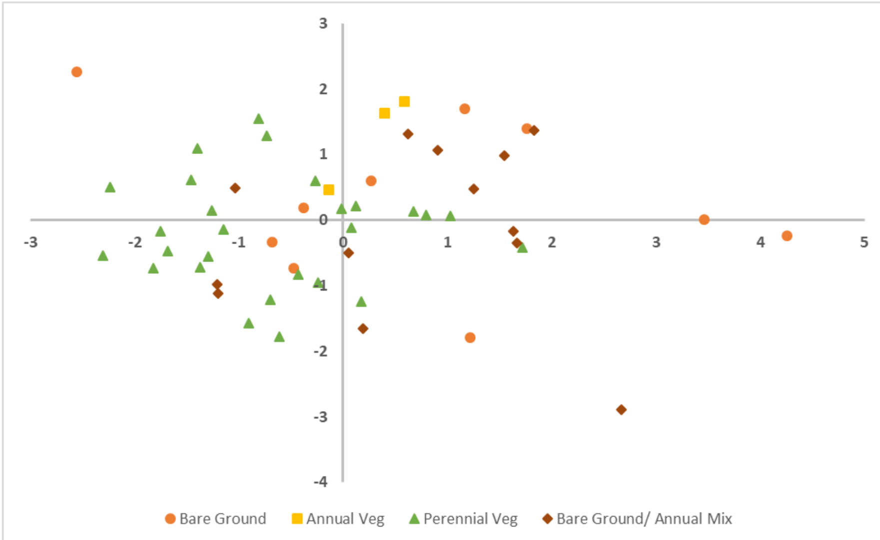

Figure 3.7 The different colored shapes represent the vegetation category of each of the 53 sites. With no significant groupings of the categories, no soil property or combination is thought to be a driving factor or vegetation cover

3.4 Conclusion

Highway shoulders in Nebraska are seeded with a mixture of seeds, dominated by perennial native grasses, with some non-native species, following construction of the highway. The highway shoulders are not ideal environments for vegetation establishment (Christen and Matlack, 2006; Godefroid and Koedam, 2004) and as many as 50% of the sampled highway shoulders across Nebraska are dominated by annual weedy species and bare ground (**Table 3.2**). Primary reasons commonly given for poor establishment of the seeded perennial grasses are the highly compacted soils at the pavement edge (shoulder) as a result of highway construction and development of saline and sodic soils over time because of the use of deicers (containing salts) during the winter (Dudley et al., 2014; Trahan and Peterson, 2007). Our survey of 53 highway shoulders across Nebraska indicates that soil compaction and salt affected soils vary by region across Nebraska, but the establishment and persistence of seeded perennial grasses do not appear to be related to the soil bulk density and salt issues of highway shoulders. We analyzed soil samples to determine if region, shoulder type and time since seeding affected soil quality and thus affected vegetation establishment.

The results of the soil survey that we conducted generally did not support our hypotheses. The study objective was to identify soil properties that may be causing a lack of vegetation along highways. We found that time since seeding and shoulder type had little effect on the selected soil properties, and vegetation growth. Region had an expected effect on soil variables as soil varies by region in Nebraska naturally, but region had no effect on vegetation cover. Soil was considered normal according to NRCS standards in the Panhandle region, but sodic in the Southcentral and Southeastern regions. Bulk densities were within a normal range in the Panhandle region and slightly high in the Southcentral and Southeastern regions, but not enough to limit vegetation growth. Since the environment is less than ideal for vegetation the lack of establishment we suggest it may be due to post seeding events and disturbances; vehicle traffic, mowing during summer months, and snowplowing in the winter may all contribute to the lack of vegetation on roadsides. At most sites throughout the state, tire tracks were seen in the soil. Mowing is done multiple times on the shoulder throughout the growing season and, based on our observations, mowing height is frequently below 15 cm (6 in), which can reduce the persistence of the vegetation along the shoulder. Snowplowing during the winter can result in “scalping” of the roadside vegetation and topsoil because of the extension of the snowplow’s blade.

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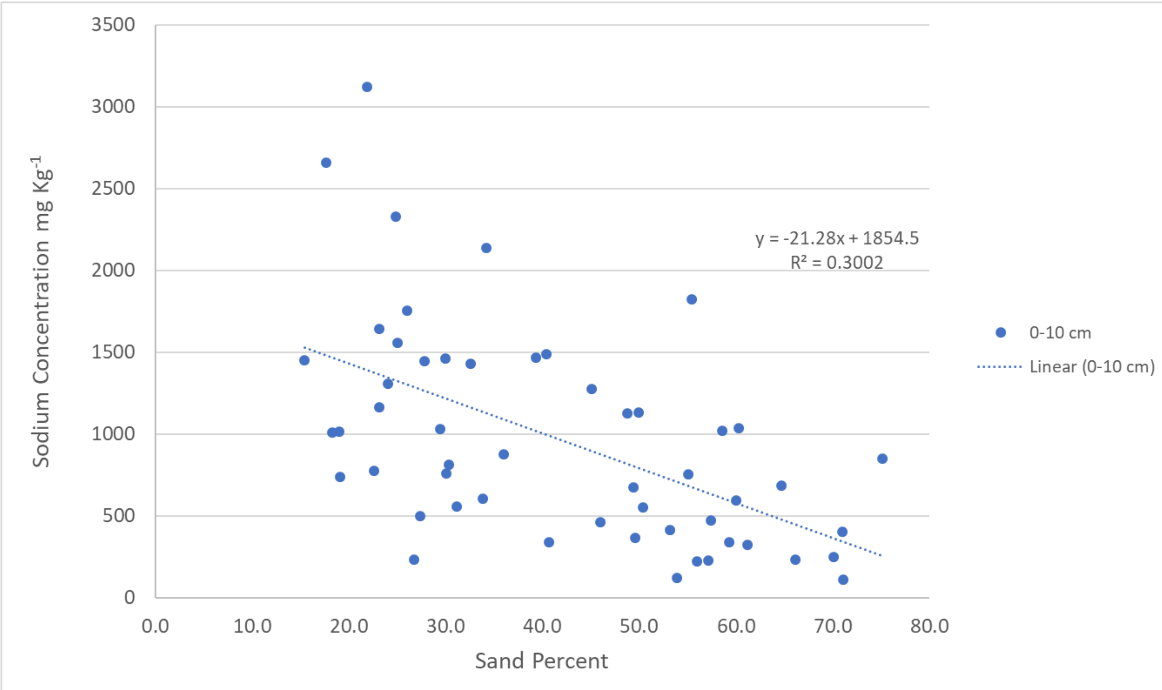
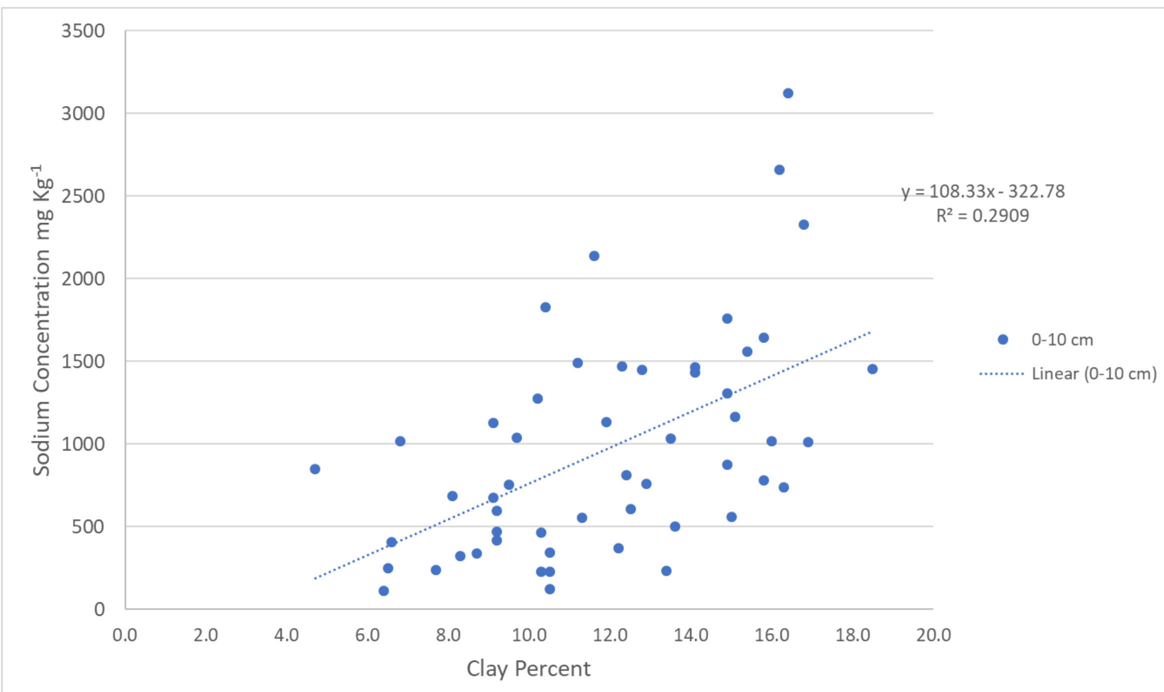
Appendix



Appendix 1 Shows the percent sand to sodium concentration for each sample taken. There was only a slight negative correlation.



Appendix 2 Shows the percent clay to sodium concentration for each sample taken. There was only a slight positive correlation.

Table 1 Shows the highway name, stretch of highway sampled, shoulder type, year category and seeding date

Region	Highway Number	Mile Marker Number	Shoulder Type	Time since Seeding (Years)	Time of Seeding (Month*,Year)
Panhandle	285	101-103	Paved	0-1	2018
	92	29-31	Paved	0-1	2018
	385	79-81	Paved	0-1	2018
	385	162-164	Paved	2-4	2014
	26	36-38	Paved	2-4	2016
	26	110-112	Paved	2-4	2014
	20	63-65	Paved	5+	2011
	385	111-113	Paved	5+	2011
	26	3-5	Paved	5+	2011
	87	22-24	Unpaved	0-1	2017
	71	96-98	Unpaved	0-1	2018
	71	105-107	Unpaved	2-4	2014
	29	36-38	Unpaved	2-4	2015
	87	57-59	Unpaved	2-4	2014
	30	53-55	Unpaved	5+	2013
	2	68-70	Unpaved	5+	2013
	71	6-8	Unpaved	5+	2009
Southcentral	283	15-16	Paved	0-1	2017
	6	93-95	Paved	0-1	2018
	2	298-300	Paved	0-1	2017
	83	29-31	Paved	2-4	2014
	83	77-79	Paved	2-4	2016
	30	205-207	Paved	2-4	2015
	6	76-78	Paved	5+	2011
	83	57-59	Paved	5+	2012
	2	273-275	Paved	5+	2012
	23	77-79	Unpaved	0-1	2018
	89	54-56	Unpaved	0-1	2017
	23	114-116	Unpaved	0-1	2017
	89	33-35	Unpaved	2-4	2015
	92	303-305	Unpaved	2-4	2014
	183	110-112	Unpaved	2-4	2015
	89	4-6	Unpaved	5+	2013
	183	102-104	Unpaved	5+	2013
	23	87-89	Unpaved	5+	2012
Southeast	15	62-64	Paved	0-1	Oct, 2017
	14	31-33	Paved	0-1	2018
	75	54-56	Paved	0-1	May, 2017
	39	38-40	Paved	2-4	Sept, 2016
	73	1-3	Paved	2-4	Aug, 2015
	92	457-459	Paved	2-4	Sept, 2016
	77	103-105	Paved	5+	Oct, 2009

	34	306-308	Paved	5+	2013
Southeast	50	57-59	Paved	5+	2010
	L63A (101)	1-3	Unpaved	0-1	2018
	14	112-114	Unpaved	0-1	2017
	112	111-113	Unpaved	0-1	Sept, 2017
	66	48-50	Unpaved	2-4	Nov, 2015
	41	97-99	Unpaved	2-4	Nov, 2015
	66	88-90	Unpaved	2-4	Sept, 2016
	79	35-37	Unpaved	5+	2009
	50	25-27	Unpaved	5+	2007
	41	53-55	Unpaved	5+	2012

* When month of seeding was known

Data File at https://unl.box.com/s/wxpingsq43jpbzjxi1reucxk6c4akbu7

Contents of File

- MetaData
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- Highway information and Data
- Bulk Density and Gravel for Depth 1
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- Soil analysis from Ward Labs Inc. Depth 1
- Soil analysis from Ward Labs Inc. Depth 2