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A Survey of Soil Properties Affecting Vegetation Establishment Along Nebraska Highways

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A SURVEY OF SOIL PROPERTIES AFFECTING VEGETATION ESTABLISHMENT ALONG NEBRASKA HIGHWAYS

by

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Vegetation along roadsides is important to prevent soil erosion, provide habitat and filter water running off the road. Along some highways in Nebraska vegetation does not readily establish and persist. It is thought that sodium and bulk density issues are the driving factor behind the lack of vegetation. After a construction project, the shoulder is seeded into the compacted soil, and salts can accumulate in the soil due to deicing agents being used during the winter. The purpose of our study was to determine if the bulk density and sodium are the driving factors of the vegetation cover. We also evaluated how shoulder type and time since seeding affected these soil issues 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% mix). It was found that sodium and compaction issues had little effect on the establishment and persistence of vegetation. Over half of the sites had high soil sodium levels at both the 0-10 and 10-20 cm depths. The bulk density was found to be normal in the Panhandle and slightly high in the Southcentral and Southeast. The shoulder and time since seeding showed limited effect on the soil variables measured. Although tested soil factors did not have large magnitude in influencing vegetation cover, we suggest post-seeding

factors such as snowplows, mowing and traffic could have contributed to the lack of vegetation along highways.

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LITERATURE REVIEW

The state of Nebraska has 16,000 kilometers of state-maintained highway running through all parts of the state (NDOT, 2016). Nebraska Department of Transportation (NDOT) is responsible for maintaining these roadways; when road projects are completed, vegetation is seeded into the roadside shoulders. Vegetation along the roadside is important for multiple reasons, including protecting against soil erosion (Chen et al., 2019; Grace, 2002), providing habitat for insects and small mammals (Ries et al., 2001; Rotholz and Mandelik, 2013), increasing infiltration of water into the soil and reducing runoff that can carry pollutants (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). Roadsides can be unsuitable ground for vegetation establishment (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). There has been research conducted on roadsides in different parts of the country to identify successful methods of establishing vegetation on the harsh conditions of roadsides. Brown and Gorres (2011) focused their research on identifying the limiting factors on roadsides and finding solutions, such as species that are tolerant of the conditions or ways to improve the conditions.

Salinity and Sodicity

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). Salts enter the soil through application of water with high salts, weathering of minerals present in the soil or organic matter decay (Jordan et al., 2004). Sodic soils are different from saline soils because they are high in only sodium ions (Qadir et al., 2001), they can be formed naturally when parent material high in sodium is weathered. Sodic soils on roadsides can be present because of the use of deicing agents containing sodium chloride. Both conditions are common and can be found on roadsides, making them saline-sodic soils. The Natural Resource Conservation Service (NRCS) of the USDA has published guidelines to classify salt affected soils. The electrical conductivity (EC) measurement is used to determine salinity, with most textures being moderately saline by 4.0 dS m^{-1} (NRCS, 2014). Sodic soils are measured using two different methods, sodium adsorption ratio (SAR) or exchangeable sodium percent (ESP). The SAR is the ratio of Na relative to Ca and Mg, a soil is considered sodic when it exceeds 13 (mmoles $1^{-1})^{0.5}$ (Zaman et al., 2018). The ESP is the fraction of Na that is found on the soil Cation Exchange Capacity (CEC). A soil is considered sodic when the ESP exceeds 15% (Zaman et al., 2018).

Saline or sodic conditions can negatively affect vegetation establishment. Maas and Grattan (1999) discussed the plant physiological effects of saline or sodic soil conditions due to nutrient imbalances or deficiencies, although visual signs may not always be present in herbaceous plants. Plants grown in saline conditions are water stressed due to increased osmotic potential, thereby reducing production (Rodriguez et al., 2005). Salinity not only affects plant growth but also can cause a reduction in chlorophyll content and/or an increase in secondary metabolite concentration in plants (Jaleel et al., 2008). An increase in soil salinity can also lead to the death of soil microorganisms. Yan et al. (2015) discussed the two primary ways microorganisms are affected, osmotic effect and ion effect. Through the osmotic effect, salts lower the osmotic potential in the soil which draws water out of the microbe's cells. The specific ion effect is when specific ions are toxic to microorganism species. Juniper and Abbott (2006) found that salinity limited growth of fungal hyphae and delayed germination of the fungi when NaCl was present. With high soil salinity, reduced water uptake and microbial activity, these salt affected soils cannot sustain vegetation that is needed to provide complete cover on roadsides.

To remediate saline soils and establish vegetation, excess salt removal and nutrient additions are essential. Walker and Bernal (2008) found that by adding organic amendments, i.e., compost and poultry manure, the SAR improved in the soil, increasing plant production and canopy cover. Dunifon et al. (2011) found that adding composted poultry manure significantly improved the quality of soil by increasing the amount of nitrogen (N), phosphorus (P), potassium (K), and organic carbon. However, the addition of organic amendments does not always decrease salt concentrations (Walker and Bernal, 2008). Arnon et al. (2006) suggested flushing the soil with water to remove salts below the rootzone and reducing high salt concentrations.

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 K on the soil CECsites. Sodium, when present in excess, can affect the soil physical properties by dispersing soil aggregates and reducing soil water infiltration (So and Aylmore, 1993). Flushing alone is not a remedy for sodic soils because the Na is held by soil CEC sites. The Na must first be replaced by other cations, such as Ca or Mg, and then Na is free to move when flushed with excess water.

Amendments can be added to the soil to improve sodic conditions. Hussain et al. (2001) applied gypsum, sulfuric acid and farmyard manure separately, and in all combinations, to plots of sodic soils followed by leaching for 30 days. They found that all treatments except farmyard manure by itself decreased Na concentration in the soil and increased wheat production when compared to the control. The combination of gypsum, sulfuric acid, and farmyard manure was the best of all treatments. Yazdanpanah et al. (2013) reported similar results with the addition of organic amendments to sodic soils, macronutrients were more readily available and microbial respiration was increased.

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 can affect the germination of grasses and forbs (Dudley et al., 2014; Zhang et al., 2012). Dudley et al. (2014) tested different types of deicer salts and found that NaCl and magnesium chloride (MgCl) salt limited germination. They also found that C_4 plant species were more tolerant of the salt than C_3 species. High Na concentration limits root uptake of K, limiting plant enzyme activity, increasing the abscisic acid production, which in turn slows photosynthesis by closing stomata (Grieve et al 2012; Zhu 2007)

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 increases osmotic stress (Grieve et al., 2012). High accumulations of Cl^- inside the plant can cause elongation of palisade cells in plant leaves and necrosis of leaves (Bernstein, 1975; Bar et al., 1987; Maas and Grattan, 1999).

Green et al. (2008) found that NaCl used on the roads as a deicing agent affected the N cycle in soil. When the Na is washed off the road, it replaces the ammonium (a source of N) that is held in by the soil CEC sites. Ke et al. (2013) found that when NaCl was added to the soil, changes to the EC, CEC, Na and Cl was 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. Microorganisms feed on plant exudates and will symbiotically give plants protection from disease, enhance plant growth and plant nutrient acquisition (Mendes et al., 2013; Raaijmakers et al., 2009).

Soil Compaction

Other than salt issues on roadsides, compaction is common factor 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). An increase in bulk density decreases pore space which slows aeration and diffusion of water, ions and gases (Horn et al., 1995). Root growth and development also is 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. An increase in or already high bulk density can affect root growth, above ground biomass production and tiller numbers (Houlbrooke et al., 1997). Barton et al. (1966) found that grass emergence and growth were reduced by high bulk density of the soil. Bartholomew and Williams (2010) reported similar results in that seedling growth was reduced with an increase in bulk density due to stunted root growth and limit in plant available water and nutrients. Parlak and Parlak (2011) found that in higher bulk density soils, plants had less N, Ca and Mg. Barik et al. (2014) found that an increase in bulk density by tractor traffic on soil decreased aggregate stability and total porosity. Dick et al., (1988) found that microbial biomass decreased in soils compacted in skid loader tracks compared to soils not compacted. Torbert and Wood (1992) reported that microbial activity decreased with increasing bulk density. Overall, soil compaction lowers soil porosity on roadsides, which can limit vegetation establishment through physically impeding root growth, decreasing nutrients and decreasing water availability.

McGrath and Henry (2016) found that compost added to roadsides decreased soil bulk density. Laird et al. (2010) found that by adding biochar to soil, bulk density was lower than unamended soils and had a higher water holding capacity. Biochar addition increased aggregate stability and saturated hydraulic conductivity of soil, thus improving drainage (Herath et al., 2013). Chen and Weil (2011) found that planting an annual cover crop increased corn yields by allowing better root penetration through compacted soils. Mohammadshirazi et al. (2017) found that tillage was a viable option to decrease bulk density and increase infiltration rate on a roadside shoulder.

Vegetation

Perennial vegetation is the desired vegetation cover along the highways for its ability to protect against erosion, provide habitat and filter runoff water (Chen et al., 2019; Ries et al., 2001; Kaighan and Yu, 1996). Annual vegetation may provide some cover during the year they grow but is not desirable because of its annual life cycle. Roadside soils can easily become disturbed or nonideal habitat which allows annual vegetation to readily establish (Pitelka, 1977; Grime, 1977), and reduce perennial vegetation production (Humphrey and Schupp, 2004). Annuals have a higher seedling growth rate than perennials (Garnier, 1992) which helps them to compete when growth of perennials is hindered. Monaco et al. (2003) found that root and shoot growth of annual grasses under low nitrogen availability was equal to or greater than that of perennial grasses. However, annual grasses do not compete well with perennial grasses when conditions are ideal or perennial vegetation is already established (Humphrey and Schupp, 2004;

Claassen and Marler, 1998). Annual grasses can adapt better to conditions that are found on roadsides, compared to perennial grasses.

Conclusion

By addressing these limiting factors of compaction and high salt concentration in the soil, we can address known problems that are causing a decrease in vegetation establishment. The addition of soil amendments and mechanical disturbance of the roadside soils are possible solution to increasing soil quality along Nebraska highways. Other factors not related to soil properties can also lead to decreased vegetation cover, these can be snowplows scalping the soil removing vegetation during the wintertime, intensive mowing during growing season or traffic on the soil. The objectives of this research are: 1) identify if salt and high bulk density factors are principal factors leading to lack of vegetation establishment, 2) identify the effect of having a paved shoulder compared to an unpaved shoulder on soil bulk density, 3) identify the effect of time-since-seeding on Na levels.

LITERATURE CITED

Akbar, K., Hale, W., & Headley, A. (2003). Assessment of scenic beauty of the roadside vegetation in northern England. *Landscape and Urban Planning*, *63*(3), 139–144. doi: 10.1016/s0169-2046(02)00185-8

Arnon, S., Ronen, Z., Yakirevich, A., & Adar, E. (2006). Evaluation of soil flushing potential for clean-up of desert soil contaminated by industrial wastewater. *Chemosphere*, *62*(1), 17–25. doi: 10.1016/j.chemosphere.2005.04.050

Bar, Y., Kafkafi, U., & Lahav, E. (1987). Nitrate nutrition as a tool to reduce chloride toxicity in avocado. In *South African Avocado Growers' Association Yearbook* (Vol. 10, pp. 47–48).

Barik, K., Aksakal, E. L., Islam, K. R., Sari, S., & Angin, I. (2014). Spatial variability in soil compaction properties associated with field traffic operations. *Catena*, *120*, 122–133. doi: 10.1016/j.catena.2014.04.013

Bartholomew, P. W., & Williams, R. D. (2010). Effects of soil bulk density and strength on seedling growth of annual ryegrass and tall fescue in controlled environment. *Grass and Forage Science*. doi: 10.1111/j.1365-2494.2010.00753.x

Barton, H., Mccully, W. G., Taylor, H. M., & Box, J. E. (1966). Influence of Soil Compaction on Emergence and First-Year Growth of Seeded Grasses. *Journal of Range Management*, *19*(3), 118. doi: 10.2307/3895391

Berli, M., Kirby, J., Springman, S., & Schulin, R. (2003). Modelling compaction of agricultural subsoils by tracked heavy construction machinery under various moisture conditions in Switzerland. *Soil and Tillage Research*, *73*(1-2), 57–66. doi: 10.1016/s0167-1987(03)00099-0

Bernstein, L. (1975). Effects of Salinity and Sodicity on Plant Growth. *Annual Review of Phytopathology*, *13*(1), 295–312. doi: 10.1146/annurev.py.13.090175.001455

Brown, R. N., & Gorres, J. H. (2011). The Use of Soil Amendments to Improve Survival of Roadside Grasses. *HortScience*, *46*(10), 1404–1410. doi: 10.21273/hortsci.46.10.1404

Chen, G., & Weil, R. R. (2011). Root growth and yield of maize as affected by soil compaction and cover crops. *Soil and Tillage Research*, *117*, 17–27. doi: 10.1016/j.still.2011.08.001

Chen, J., Xiao, H., Li, Z., Liu, C., Wang, D., Wang, L., & Tang, C. (2019). Threshold effects of vegetation coverage on soil erosion control in small watersheds of the red soil hilly region in China. *Ecological Engineering*, *132*, 109–114. doi: 10.1016/j.ecoleng.2019.04.010

Christen, D., & Matlack, G. (2006). The Role of Roadsides in Plant Invasions: a Demographic Approach. *Conservation Biology*, *20*(2), 385–391. doi: 10.1111/j.1523-1739.2006.00315.x

Claassen, V. P., & Marler, M. (1998). Annual and Perennial Grass Growth on Nitrogen-Depleted Decomposed Granite. *Restoration Ecology*, *6*(2), 175–180. doi: 10.1046/j.1526-100x.1998.00629.x

Dick, R. P., Myrold, D. D., & Kerle, E. A. (1988). Microbial Biomass and Soil Enzyme Activities in Compacted and Rehabilitated Skid Trail Soils. *Soil Science Society of America Journal*, *52*(2), 512. doi: 10.2136/sssaj1988.03615995005200020038x

Dudley, M. M., Jacobi, W. R., & Brown, C. S. (2014). Roadway Deicer Effects on the Germination of Native Grasses and Forbs. *Water, Air, & Soil Pollution*, *225*(6). doi: 10.1007/s11270-014-1984-z

Dunifon, S. N., Evanylo, G. K., Maguire, R. O., & Goatley, J. M. (2011). Soil Nutrient and Fescue (Festucaspp.) Responses To Compost and Hydroseed on a Disturbed Roadside. *Compost Science & Utilization*, *19*(3), 147–151. doi: 10.1080/1065657x.2011.10736993

Fathi, M & Masnavi, Mohammad. (2014). Assessing Environmental Aesthetics of Roadside Vegetation and Scenic Beauty of Highway Landscape: Preferences and Perception of Motorists. International Journal of Environmental Research. 8. 941-952.

Forman, R. T. T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., … Winter, T. C. (2003). *Road ecology: science and solutions*. Washington, DC: Island Press.

Garnier, E. (1992). Growth Analysis of Congeneric Annual and Perennial Grass Species. *The Journal of Ecology*, *80*(4), 665. doi: 10.2307/2260858

Godefroid, S., & Koedam, N. (2004). The impact of forest paths upon adjacent vegetation: effects of the path surfacing material on the species composition and soil compaction. *Biological Conservation*, *119*(3), 405–419. doi: 10.1016/j.biocon.2004.01.003

Grace , J. M. (2002). Effectiveness Of Vegetation In Erosion Control From Forest Road Sideslopes. *Transactions of the ASAE, 45*(3). doi: 10.13031/2013.8832

Green, S. M., Machin, R., & Cresser, M. S. (2008). Effect of long-term changes in soil chemistry induced by road salt applications on N-transformations in roadside soils. *Environmental Pollution*, *152*(1), 20–31. doi: 10.1016/j.envpol.2007.06.005

Grieve, C.M., S.R. Grattan and E.V. Maas. 2012. Plant salt tolerance. In: W.W. Wallender and K.K. Tanji (eds.) ASCE Manual and Reports on Engineering Practice No. 71 Agricultural Salinity Assessment and Management (2nd Edition). ASCE, Reston, VA. Chapter 13 pp:405-459.

Grime, J. P. (1977). Evidence for the Existence of Three Primary Strategies in Plants and Its Relevance to Ecological and Evolutionary Theory. *The American Naturalist*, *111*(982), 1169–1194. doi: 10.1086/283244

Haan, N. L., Hunter, M. R., & Hunter, M. D. (2011). Investigating Predictors of Plant Establishment During Roadside Restoration. *Restoration Ecology*, *20*(3), 315–321. doi: 10.1111/j.1526-100x.2011.00802.x

Herath, H., Camps-Arbestain, M., & Hedley, M. (2013). Effect of biochar on soil physical properties in two contrasting soils: An Alfisol and an Andisol. *Geoderma, 209-210*, 188–197. doi: 10.1016/j.geoderma.2013.06.016

Horn, R., Domżżał, H., Słowińska-Jurkiewicz, A., & Ouwerkerk, C. V. (1995). Soil compaction processes and their effects on the structure of arable soils and the environment. *Soil and Tillage Research*, *35*(1-2), 23–36. doi: 10.1016/0167-1987(95)00479-c

Houlbrooke, D. J., Thom, E. R., Chapman, R., & Mclay, C. D. A. (1997). A study of the effects of soil bulk density on root and shoot growth of different ryegrass lines. *New Zealand Journal of Agricultural Research*, *40*(4), 429–435. doi: 10.1080/00288233.1997.9513265

Humphrey, L. D., & Schupp, E. W. (2004). Competition as a barrier to establishment of a native perennial grass (*Elymus elymoides*) in alien annual grass (*Bromus tectorum*) communities. *Journal of Arid Environments*, *58*(4), 405–422. doi: 10.1016/j.jaridenv.2003.11.008

Hussain, N., Arshadullah, M., & Hamdy, G. (2001). Evaluation of Amendments for the Improvement of Physical Properties of Sodic Soil. *International Journal Agriculture and Biology*, *3*(3), 319–322.

Jaleel, C. A., Sankar, B., Sridharan, R., & Panneerselvam, R. (2008). Soil Salinity Alters Growth, Chlorophyll Content, and Secondary Metabolite Accumulation in Catharanthus roseus. *Turkish Journal of Biology*, *32*, 79–83.

Jordán, M. M., Navarro-Pedreño, J., García-Sánchez, E., Mateu, J., & Juan, P. (2004). Spatial dynamics of soil salinity under arid and semi-arid conditions: geological and environmental implications. *Environmental Geology*, *45*(4), 448–456. doi: 10.1007/s00254-003-0894-y

Juniper, S., & Abbott, L. K. (2006). Soil salinity delays germination and limits growth of hyphae from propagules of arbuscular mycorrhizal fungi. *Mycorrhiza*, *16*(5), 371–379. doi: 10.1007/s00572-006-0046-9

Kaighn, R. J., & Yu, S. L. (1996). Testing of Roadside Vegetation for Highway Runoff Pollutant Removal. *Transportation Research Record: Journal of the Transportation Research Board*, *1523*(1), 116–123. doi: 10.1177/0361198196152300114

Ke, C., Li, Z., Liang, Y., Tao, W., & Du, M. (2013). Impacts of chloride de-icing salt on bulk soils, fungi, and bacterial populations surrounding the plant rhizosphere. *Applied Soil Ecology*, *72*, 69–78. doi: 10.1016/j.apsoil.2013.06.003

Keller, L. P., Mccarthy, G. J., & Richardson, J. L. (1986). Mineralogy and Stability of Soil Evaporites in North Dakota1. *Soil Science Society of America Journal*, *50*(4), 1069. doi: 10.2136/sssaj1986.03615995005000040047x

Laird, D. A., Fleming, P., Davis, D. D., Horton, R., Wang, B., & Karlen, D. L. (2010). Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*, *158*(3-4), 443–449. doi: 10.1016/j.geoderma.2010.05.013

Maas, E. V., & Grattan, S. R. (1999). Crop Yields as Affected by Salinity. *Agricultural Drainage Agronomy Monograph*. doi: 10.2134/agronmonogr38.c3

Mcgrath, D., & Henry, J. (2016). Organic amendments decrease bulk density and improve tree establishment and growth in roadside plantings. *Urban Forestry & Urban Greening*, *20*, 120–127. doi: 10.1016/j.ufug.2016.08.015

Mendes, R., Garbeva, P., & Raaijmakers, J. M. (2013). The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. *FEMS Microbiology Reviews*, *37*(5), 634–663. doi: 10.1111/1574-6976.12028

Mohammadshirazi, F., Mclaughlin, R. A., Heitman, J. L., & Brown, V. K. (2017). A multi-year study of tillage and amendment effects on compacted soils. *Journal of Environmental Management*, *203*, 533–541. doi: 10.1016/j.jenvman.2017.07.031

Monaco, T. A., Johnson, D. A., Norton, J. M., Jones, T. A., Connors, K. J., Norton, J. B., & Redinbaugh, M. B. (2003). Contrasting Responses of Intermountain West Grasses to Soil Nitrogen. *Journal of Range Management*, *56*(3), 282. doi: 10.2307/4003820

Naidu, R., & Rengasamy, P. (1993). Ion interactions and constraints to plant nutrition in Australian sodic soils. *Soil Research, 31*(6), 801. doi: 10.1071/sr9930801

Natural Resource Conservation Service. (2014). *Soil Electrical Conductivity.* Soil Health – Guide for Educators.

NDOT, 2016. Some Facts and Figures from the Nebraska Department of Roads.

NDOT, 2017. Standard Specifications For Highway Construction

Parlak, M., & Parlak, A. O. (2011). Effect of Soil Compaction on Root Growth and Nutrient Uptake of Forage Crops. *Journal of Food, Agriculture & Environment*, *9*, 275–278.

Pitelka, L. F. (1977). Energy Allocations in Annual and Perennial Lupines (lupinus: Leguminosae). *Ecology*, *58*(5), 1055–1065. doi: 10.2307/1936925

Qadir, M., Schubert, S., Ghafoor, A., & Murtaza, G. (2001). Amelioration strategies for sodic soils: a review. *Land Degradation & Development*, *12*(4), 357–386. doi: 10.1002/ldr.458

Raaijmakers, J. M., Paulitz, T. C., Steinberg, C., Alabouvette, C., & Moënne-Loccoz, Y. (2008). The rhizosphere: a playground and battlefield for soilborne pathogens and beneficial microorganisms. *Plant and Soil*, *321*(1-2), 341–361. doi: 10.1007/s11104-008-9568-6

Rengasamy, P., & Walters, L. (1994). *Introduction to soil sodicity* . Cooperative Research Centre for Soil & Land Management.

Ries, L., Debinski, D. M., & Wieland, M. L. (2001). Conservation Value of Roadside Prairie Restoration to Butterfly Communities. *Conservation Biology*, *15*(2), 401–411. doi: 10.1046/j.1523-1739.2001.015002401.x

Rodriguez, P., Torrecillas, A., Morales, M., Ortuno, M., & Sanchezblanco, M. (2005). Effects of NaCl salinity and water stress on growth and leaf water relations of plants. *Environmental and Experimental Botany*, *53*(2), 113–123. doi: 10.1016/j.envexpbot.2004.03.005

Rotholz, E., & Mandelik, Y. (2013). Roadside habitats: effects on diversity and composition of plant, arthropod, and small mammal communities. *Biodiversity and Conservation*, *22*(4), 1017–1031. doi: 10.1007/s10531-013-0465-9

Rutter, A. J., & Thompson, J. R. (1986). The Salinity of Motorway Soils. III. Simulation of the Effects of Salt Usage and Rainfall on Sodium and Chloride Concentrations in the Soil of Central Reserves. *The Journal of Applied Ecology*, *23*(1), 281. doi: 10.2307/2403097

Seeling, B.D. (2000). *Salinity and Sodicity in North Dakota Soils*. North Dakota State University Extension Service Publication.

Skinner, A. K., Lunt, I. D., Spooner, P., & Mcintyre, S. (2009). The effect of soil compaction on germination and early growth ofEucalyptus albensand an exotic annual grass. *Austral Ecology*, *34*(6), 698–704. doi: 10.1111/j.1442-9993.2009.01977.x

So, H., & Aylmore, L. (1993). How do sodic soils behave - the effects of sodicity on soil physical behavior. *Soil Research*, *31*(6), 761. doi: 10.1071/sr9930761

Sveistrup, T. E., & Haraldsen, T. K. (1997). Effects of soil compaction on root development of perennial grass leys in northern Norway. *Grass and Forage Science*, *52*(4), 381–387. doi: 10.1111/j.1365-2494.1997.tb02370.x

Thompson, J. R., Rutter, A. J., & Ridout, P. S. (1986). The Salinity of Motorway Soils. I. Variation in Time and Between Regions in the Salinity of Soils on Central Reserves. *The Journal of Applied Ecology*, *23*(1), 251. doi: 10.2307/2403095

Torbert, H. A., & Wood, C. W. (1992). Effects of soil compaction and water-filled pore space on soil microbial activity and N losses. *Communications in Soil Science and Plant Analysis*, *23*(11-12), 1321–1331. doi: 10.1080/00103629209368668

Unger, P. W., & Kaspar, T. C. (1994). Soil Compaction and Root Growth: A Review. *Agronomy Journal*, *86*(5), 759. doi: 10.2134/agronj1994.00021962008600050004x

Walker, D. J., & Bernal, M. P. (2008). The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil. *Bioresource Technology*, *99*(2), 396–403. doi: 10.1016/j.biortech.2006.12.006

White, P. J., & Broadley, M. R. (2001). Chloride in Soils and its Uptake and Movement within the Plant: A Review. *Annals of Botany*, *88*(6), 967–988. doi: 10.1006/anbo.2001.1540

Yan, N., Marschner, P., Cao, W., Zuo, C., & Qin, W. (2015). Influence of salinity and water content on soil microorganisms. *International Soil and Water Conservation Research*, *3*(4), 316–323. doi: 10.1016/j.iswcr.2015.11.003

Yazdanpanah, N., & Mahmoodabadi, M. (2011). Reclamation of calcareous saline–sodic soil using different amendments: Time changes of soluble cations in leachate. *Arabian Journal of Geosciences*, *6*(7), 2519–2528. doi: 10.1007/s12517-011-0505-2

Zaman, M., Shahid, S. A., & Heng, L. (2018). *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*. Cham: Springer International Publishing.

Zhang, Q., Rue, K., & Wang, S. (2012). Salinity Effect on Seed Germination and Growth of Two Warm-season Native Grass Species. *HortScience*, *47*(4), 527–530. doi: 10.21273/hortsci.47.4.527

Zhu, J. (2001). Plant Salt Stress. *Encyclopedia of Life Sciences*. doi: 10.1038/npg.els.0001300

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ABSTRACT

Vegetation along roadsides is important to prevent soil erosion, provide habitat and filter water running off the road. Along some highways in Nebraska vegetation does not readily establish and persist. It is thought that sodium and bulk density issues are the driving factor behind the lack of vegetation. After a construction project, the shoulder is seeded into the compacted soil, and salts can accumulate in the soil due to deicing agents being used during the winter. The purpose of our study was to determine if the bulk density and sodium are the driving factors of the vegetation cover. We also evaluated how shoulder type and time since seeding affected these soil issues 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% mix). It was found that sodium and compaction issues had little effect on the establishment and persistence of vegetation. Over half of the sites had high soil sodium levels at both the 0-10 and 10-20 cm depths. The bulk density was found to be normal in the Panhandle and slightly high in the Southcentral and Southeast. The shoulder and time since seeding showed limited effect on the soil variables measured. Although tested soil factors did not have large magnitude in influencing vegetation cover, we suggest post-seeding factors such as snowplows, mowing and traffic could have contributed to the lack of vegetation along highways.

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

1. Introduction

The Nebraska Department of Transportation (NDOT) is responsible for maintaining 16,000 km of highways (NDOT 2016). Road construction projects create bare soil on roadside shoulders after completion of construction. The shoulders are seeded to a mixture of grasses to provide ground cover. If projects have a stormwater permit and once seeded, roadsides are monitored until perennial vegetation cover is 70% 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).

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 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 sodium ions (Qadir et al., 2001). Saline and sodic soils on roadsides can develop from the use of deicing salts which are carried to roadside shoulders by snow melt and rain (Haan, 2012; Thompson et al., 1986; Rutter and Thompson, 1986). Roadway deicing salts, especially 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) on soils cation exchange capacity (CEC) sites, this created an imbalance of ion distributions on the CEC and a reduction in other essential nutrients. Ke et al. (2013) found that when NaCl was added to the soil, changes to the electrical conductivity (EC), CEC, Na and Cl were strongly correlated with negative changes in microbial populations. Some microorganisms are not able to survive in an environment with an increase in sodium. Juniper and Abbot (2006) reported a similar reduction of fungal and bacteria population surrounding the plant rhizosphere when NaCl was added to the soil.

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). High Na concentration limits root uptake of K, which limits plant enzyme activity, increasing 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 through aggregate dispersion and reduced 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).

Other than salt issues on roadsides, compaction is a 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 limits water infiltration (Berli et al., 2003). An increase in bulk density can decrease pore space, slow aeration and slow diffusion of water, ions, and gases (Horn et al. 1995). Root growth and development also are 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 affects root growth, but 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).

There has been research conducted on roadsides in different parts of the country addressing the objective of establishing perennial vegetation on the roadside environments. Due to the concerns of NDOT, the objective of our study was to identify if Na and compaction issues are driving factors of the lack of vegetation along highways. The effect that time since seeding and shoulder type (paved vs unpaved) had on soils properties at two depths in three regions of Nebraska were also 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 sodium and lower bulk density, than unpaved shoulders; and that time since seeding would allow for greater accumulation of sodium levels in at older sites.

2. Materials and Methods

2.1 Study Locations

Soil samples were collected in three different 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 (NDOT, 2019; Fig. 1).

2.2 Southeastern Region

The Southeastern region is in the loess and glacial drift ecoregion (Fig. 1). The climate is a hot summer humid continental climate (Köppen, 1936) with an average annual high and low temperature of 17.3° C and 4.4° C, respectively. The average annual precipitation for the Southeastern region is 735 mm with 73% as rainfall during the growing season (April through September). 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) (Nebraska Soil Association Map, Elder, 1969). 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).*

2.3 Southcentral Region

The Southcentral region is in the central loess plains ecoregion and covers the central portion south of the Sandhills (Fig. 1). The climate is a hot summer, humid continental to humid subtropical (Köppen, 1936) with an average annual high temperature of 16.5° C and an average annual low of 1.7° C. The average annual precipitation for the Southcentral region is 528 mm with 77% as rainfall during the growing season. The three prevalent soil associations 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) (Elder, 1969).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).*

2.4 Panhandle Region

The Panhandle is in the high plains ecoregion of western Nebraska (Fig. 1). The climate is classified as cold and semi-arid (Köppen, 1936) with an annual average high temperature of 17.5° C and an average low of 1.1° C. The average annual precipitation for the Panhandle is 400 mm with 73% as rainfall during the growing season. The three prevalent associations 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) (Elder, 1969). 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).*

2.5 Study Design

The shoulder is the area that is paved or unpaved directly next to the road and sits above the front slope and ditch (Fig. 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 after vegetation is established on the shoulder. Highway shoulders varied by sites, paved shoulders varied from 1.8 to 2.4 m of pavement next to the highway lane with unpaved shoulders having 0.3 m or less of pavement next to the highway lane. During the construction process soil is compacted to provide a stable foundation for the pavement.

Study sites within each region were identified in 2018 with the assistance of employees from NDOT (Appendix, Table 1). Each site, constituting as a roadway/highway, was categorized according to time since seeding (year categories: 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 in 17 sites (Fig. 1).

Soil samples were collected from three locations along the highway at a 1.6 km interval. Samples were collected from each site using a JMC Backsaver (Clements Associates, Inc., Newton, IA) soil probe, during May of 2019. Two depth intervals, 0-10 cm and 10-20 cm, were collected using zero contamination plastic sleeves 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 heavy traffic effect, 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 placed in a freezer at -10.1° C, until lab analyses. Samples were thawed 24 hours before analysis.

2.6 Measuring Soil Properties

Cores were split into 0-10, and 10-20 cm increments, and initial weight was recorded. Soil at each depth was oven dried at 105° C 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; and then soil samples were re-weighed. The new weight was subtracted from the initial dry weight to calculate gravel weight, which was divided by the initial dry weight to calculate gravel percent per sample.

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, (percent clay and silt were determined from the distribution Soil Science Division Staff, 2017).

2.7 Categorization of Vegetation Cover

Vegetation cover along roadsides can be variable throughout the state. The cover was evaluated at the time of soil sampling in early May through observation of the first meter off the pavement at each site. Four categories were used in the evaluation; (1) bare ground was greater than 70%, (2) Perennial grass cover was greater than 50%, (3) Weedy annuals, forbs and grasses was greater than >70%, (4) Weedy annual and bare ground mix was approximately 50-50% (Fig. 3). These categories were used to determine if soil variables had any influence on the type of cover present at each site.

2.8 Statistical Analysis

Analysis was performed using SAS 9.4 statistical software (SAS Institute, 2012). The mixed model type I 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.

3. Results

3.1 Chemical Properties

Sodium concentration in the soil varied significantly by region at both depth intervals (Fig. 4a). At the 0-10 cm depth, the Panhandle region had one-third to one-half the amount of Na (480 mg kg^{-1}) than the Southcentral and Southeastern regions (986 and 1413 mg kg^{-1}, respectively). At the 10-20 cm depth, soil Na concentration in the Panhandle region was two to three times lower (520 mg kg^{-1}) than in the Southcentral and Southeastern regions (1034 and 1818 mg kg^{-1} respectively). At the 0-10 cm depth, soil Na concentration also differed between shoulder types (Fig. 4b) but not by year. The soil Na concentration for the unpaved shoulder (1137 mg kg^{-1}) was about 50% greater than that of the paved shoulders (782 mg kg^{-1}). There was a shoulder (Fig. 4b) and year (Fig. 4c) effect at the 10-20 cm depth. At this depth, the Na concentration of the unpaved shoulders (1410 mg kg^{-1}) was nearly 75% greater than that of the paved shoulders (838 mg kg^{-1}). The soil Na concentration for the 0-1 year-old-sites (827 mg kg^{-1}) was less than the 2-4 year and 5+ year-old-sites (1225 and 1319 mg kg^{-}1, respectively).

Soil exchangeable sodium percent (ESP) varied by region also. 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 0-10 cm depth. For the 10-20 cm depth, 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.

Electrical conductivity at the 0-10 cm depth differed by region (Fig. 5a) and shoulder type (Fig. 5b). The EC in the Panhandle region (0.11 dS m^{-1}) was two to 3.5 times less compared to the Southcentral and Southeastern regions (0.28 and 0.39 dS m^{-1}, respectively); and EC of soil on the paved shoulder type (0.21 dS m^{-1}) was one-third less than it was for the soil from an unpaved shoulder (0.30 dS m^{-1}). Region and shoulder type also affected EC of soil at the depth of 10-20 cm (Fig. 5). Electrical conductivity of soils from 10-20 cm in the Southeastern region (2.07 dS m^{-1}) was about two times greater than that from the Panhandle and Southcentral regions (0.87 and 1.09 dS m^{-1}, respectively). The EC on the paved shoulder (0.97 dS m^{-1}) was about half that of the unpaved shoulder (1.72 dS m^{-1}). Year was not significant at either soil depth for EC.

Chloride had a regional effect and showed a west to east gradient (Fig. 6). The Panhandle region was 2.5 to almost five times lower than the other two regions at both depths (150 and 187 mg kg^{-1}, for 0-10 and 10-20 cm respectively). The Southcentral region had concentrations of 384 and 488 mg kg^{-1} for 0-10 and 10-20 cm, respectively, while the Southeast region had 734 and 995 mg kg^{-1} for 0-10 and 10-20 cm, respectively.

At the 10-20 cm depth, pH was found to be significant only by region (Fig. 7). 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 by shoulder by region was significant for the 0-10 cm depth (Fig. 8). 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).

3.2 Physical Properties

Bulk density averaged 1.4 Mg m^{-3} and 1.5 Mg m^{-3} across all sites for soil depths of 0-10 and 10-20 cm, respectively. Gravel content averaged 16.4% and 10% across all sites for soil depths of 0-10 and 10-20 cm, 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 Southeastern region, averaged across sampling locations, 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 texture at the Panhandle region averaged 57% sand and 10% clay.

3.3 Vegetation Cover

The categorization showed that 50% of the 53 sites sampled had perennial vegetation established (Table 1). There were no tight groupings of any vegetation cover types on the principal components analysis (PCA), so we concluded that pH, Na, EC, bulk density or any combination of these variables did not explain the type of vegetation cover found at the sampled sites (Fig. 9). This nullifies our hypothesis that vegetation type was driven by Na or bulk density.

4. Discussion

Highway shoulders in Nebraska are seeded to a seeding mixture dominated by perennial native grasses following construction of the highway. The highway shoulders do not have optimal soil environments for vegetation establishment (Christen and Matlack, 2006; Godefroid and Koedam, 2004) and as many as 50% of highway shoulders across Nebraska are dominated by annual weedy species and bare ground (Table 1). 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 the 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 indicated 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 soil salt issues of highway shoulders.

4.1 Chemical properties

Soil Na concentration differed by region at both the 0-10 cm and 10-20 cm depths (Fig. 3a), with the Panhandle region having a lower Na concentration compared to the other two regions. Although, we expected that the Panhandle region would have lower soil Na content because of sandier textures, there was no correlation between the percentage sand and the soil Na concentrations (Appendix, Fig. 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, Fig. 2). Although there was no correlation between clay and Na we did see high sodium levels in the southeast region which had the highest clay percent.

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. For example, the Panhandle region had 27 days with an average high temperature under 0° C from November 2018 to March 2019 and an average of 27 days over the past five years. The Southcentral and Southeastern regions had 64 and 51 days with an average high temperature under 0° C from November 2018 to March 2019, respectively and a five year average of 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) The frequency and amount of deicer material applied is not recorded/known by region. The amount of brine solution applied 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 need to be quantified.

Highways with unpaved shoulders had a greater concentration of Na in the soil than paved shoulders (Fig. 4b). 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 of roadway where the water carrying salts can evaporate from the shoulder and deposit less salt in the adjacent soil. Roads are also built to allow water to runoff, with a paved shoulder the pavement may extend far enough down the slope that NaCl 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.

There was a time year effect for Na concentrations for the 10-20 cm depth. This could be due to accumulation of sodium overtime. Due to precipitation events and runoff over the years the Na may be carried down the soil before it is attached to CEC sites, resulting in this effect for the 10-20 cm depth and not the 0-10 cm depth.

The EC at 0-10 cm and 10-20 cm depths were found to be different among regions (Fig. 5a), and although differences were significant, the EC levels 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 dS m^{-1}, respectively (NRCS, 2014). The EC across all regions was below these values given in the NRCS guide. The lower EC value measured in the Panhandle region could be due to its sandier texture allowing water to carry salt below the rootzone and reducing Na and other salt concentrations in the 0-10 cm soil depth. This can be seen as EC was greater for the 10-20 depth than the 0-10 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) Due to the negative charge of Cl^- ions, they are not held on CEC sites and more readily carried by water out of the root zone. Sandier-textured-soils have a lower CEC compared to silty and clay textures and cannot hold on to as many ions (Ketterings et al., 2007).

The shoulder type also affected EC at the 0-10 cm and the 10-20 cm depths (Fig. 5b). The EC difference by shoulder type in the soil was likely similar to that of Na concentration difference. 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.

Soil pH at the 10-20 cm depth differed by region. The soil pH in the Panhandle region was significantly higher than the other two regions (Fig. 7). 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 by time since seeding by shoulder for pH at the 0-10 cm soil depth (Fig. 8). 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).

The soil ESP is a representation of the fraction of Na present on the soil CEC sites. 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 condition (Fig. 10). Based on ESP, EC, and pH, the roadside soils at the Panhandle region were within the normal soil category, below the 15% threshold but higher than a normal Nebraska soil. The soils in Southcentral and Southeastern regions were in the sodic category. There were 29 sites at both depths in the sodic category (Table 2). Sodium is a dispersing agent and when in high concentrations on the CEC sites it can degrade the physical structure of the soil. The structure of the soil at our sampling sites were not tested for structure integrity. However, our preliminary data from other roadside soils indicated a small proportion of macroaggregates, 7% along the road compared to 80% in the ditch (Mills, unpublished data).

Time since seeding was evaluated but was not found to have significant effect on any soil chemical properties that were analyzed except Na concentration for 10-20 cm. We expected higher EC and ESP for the 5+ years since seeding, however, the lack of year effect on the EC could be due to the ions being leached below the sampling depths.

4.2 Physical Properties

Bulk density and gravel percent were not affected by the main effects. We had hypothesized that shoulder type would affect soil bulk density, with relatively high bulk densities 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 of pavement edge did not differ between paved and unpaved shoulders. Time since seeding also had no effect on bulk density.

In the Panhandle region the bulk densities ranged from 1.33 to 1.46 Mg m^{-3}, respectively. With the sandy loam textures in the Panhandle region, these 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 Mg m^{-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 Mg m^{-3}, respectively. These values would be considered slightly high but not root limiting (NRCS, 2019).

A reason for the high bulk densities could be due to traffic driving 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 reasoning 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 are mixed with 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.

4.3 Vegetation

Category of vegetation cover on the shoulders was not explained by any single soil variable or combination of the tested soil variables. Highway shoulders are not a conducive environment 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 N concentration and ESP 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 non-optimal growing conditions. Once the vegetation is seeded on the roadsides, there are many factors that can influence the growth and production in the first meter off the pavement, whether there is a paved shoulder or not. 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 which can move soil and displace or destroy vegetation (Ayers, 1994). 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 are 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.

Lack of vegetation may also be contributed to seed viability of purchased seed. If seed purchased for a project has low germination rate, then a whole project planting may be compromised. In an unpublished study, we observed 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 low 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).

5. Conclusion

The results generally did not support our hypotheses. The study objective was to identify soil properties (pH, EC, Na and bulk density) that explain the 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 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 factors did not explain the lack of vegetation, we suggest that it may be due to post seeding events. 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 observed 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, which can reduce the persistence of the vegetation along the shoulder. Snowplowing during the winter was observed to include more than removing snow from paved surfaces but “scalping” of the roadside vegetation and topsoil because of the extension of the snowplow’s blade.

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LITERATURE CITED

Akbar, K., Hale, W., & Headley, A. (2003). Assessment of scenic beauty of the roadside vegetation in northern England. *Landscape and Urban Planning*, *63*(3), 139–144. doi: 10.1016/s0169-2046(02)00185-8

American Public Works Association, 2016. Brine Fact Sheet

Arriaga, F. J., Lowery, B., & Mays, M. D. (2006). A Fast Method For Determining Soil Particle Size Distribution Using A Laser Instrument. *Soil Science*, *171*(9), 663–674. doi: 10.1097/01.ss.0000228056.92839.88

Ayers, P. (1994). Environmental damage from tracked vehicle operation. *Journal of Terramechanics*, *31*(3), 173–183. doi: 10.1016/0022-4898(94)90014-0

Bartholomew, P. W., & Williams, R. D. (2010). Effects of soil bulk density and strength on seedling growth of annual ryegrass and tall fescue in controlled environment. *Grass and Forage Science*. doi: 10.1111/j.1365-2494.2010.00753.x

Barton, H., Mccully, W. G., Taylor, H. M., & Box, J. E. (1966). Influence of Soil Compaction on Emergence and First-Year Growth of Seeded Grasses. *Journal of Range Management, 19*(3), 118. doi: 10.2307/3895391

Berli, M., Kirby, J., Springman, S., & Schulin, R. (2003). Modelling compaction of agricultural subsoils by tracked heavy construction machinery under various moisture conditions in Switzerland. *Soil and Tillage Research*, *73*(1-2), 57–66. doi: 10.1016/s0167-1987(03)00099-0

Chen, J., Xiao, H., Li, Z., Liu, C., Wang, D., Wang, L., & Tang, C. (2019). Threshold effects of vegetation coverage on soil erosion control in small watersheds of the red soil hilly region in China. *Ecological Engineering*, *132*, 109–114.

Christen, D., & Matlack, G. (2006). The Role of Roadsides in Plant Invasions: a Demographic Approach. *Conservation Biology*, *20*(2), 385–391. doi: 10.1111/j.1523-1739.2006.00315.x

Dudley, M. M., Jacobi, W. R., & Brown, C. S. (2014). Roadway Deicer Effects on the Germination of Native Grasses and Forbs. *Water, Air, & Soil Pollution*, *225*(6). doi: 10.1007/s11270-014-1984-z

Elder, J. A. (1969). *Soils of Nebraska*. Lincoln: University of Nebraska Conservation and Survey Division.

Fathi, M & Masnavi, Mohammad. (2014). Assessing Environmental Aesthetics of Roadside Vegetation and Scenic Beauty of Highway Landscape: Preferences and Perception of Motorists. International Journal of Environmental Research. 8. 941-952.

Forman, R. T. T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., … Winter, T. C. (2003). *Road ecology: science and solutions*. Washington, DC: Island Press.

Godefroid, S., & Koedam, N. (2004). The impact of forest paths upon adjacent vegetation: effects of the path surfacing material on the species composition and soil compaction. *Biological Conservation*, *119*(3), 405–419. doi: 10.1016/j.biocon.2004.01.003

Grace , J. M. (2002). Effectiveness Of Vegetation In Erosion Control From Forest Road Sideslopes. *Transactions of the ASAE*, *45*(3).

Green, S. M., Machin, R., & Cresser, M. S. (2008). Effect of long-term changes in soil chemistry induced by road salt applications on N-transformations in roadside soils. *Environmental Pollution*, *152*(1), 20–31. doi: 10.1016/j.envpol.2007.06.005

Grieve, C.M., S.R. Grattan and E.V. Maas. 2012. Plant salt tolerance. In: W.W. Wallender and K.K. Tanji (eds.) ASCE Manual and Reports on Engineering Practice No. 71 Agricultural Salinity Assessment and Management (2nd Edition). ASCE, Reston, VA. Chapter 13 pp:405-459.

Guglielmini, L., Gontcharov, A., Aldykiewicz, A. J., & Stone, H. A. (2008). Drying of salt solutions in porous materials: Intermediate-time dynamics and efflorescence. *Physics of Fluids*, *20*(7), 077101. doi: 10.1063/1.2954037

Haan, N. L., Hunter, M. R., & Hunter, M. D. (2011). Investigating Predictors of Plant Establishment During Roadside Restoration. *Restoration Ecology*, *20*(3), 315–321. doi: 10.1111/j.1526-100x.2011.00802.x

Horn, R., Domżżał, H., Słowińska-Jurkiewicz, A., & Ouwerkerk, C. V. (1995). Soil compaction processes and their effects on the structure of arable soils and the environment. *Soil and Tillage Research*, *35*(1-2), 23–36. doi: 10.1016/0167-1987(95)00479-c

Houlbrooke, D. J., Thom, E. R., Chapman, R., & Mclay, C. D. A. (1997). A study of the effects of soil bulk density on root and shoot growth of different ryegrass lines. *New Zealand Journal of Agricultural Research*, *40*(4), 429–435. doi: 10.1080/00288233.1997.9513265

Jaleel, C. A., Sankar, B., Sridharan, R., & Panneerselvam, R. (2008). Soil Salinity Alters Growth, Chlorophyll Content, and Secondary Metabolite Accumulation in Catharanthus roseus. *Turkish Journal of Biology*, *32*, 79–83.

Juniper, S., & Abbott, L. K. (2006). Soil salinity delays germination and limits growth of hyphae from propagules of arbuscular mycorrhizal fungi. *Mycorrhiza*, *16*(5), 371–379. doi: 10.1007/s00572-006-0046-9

Kaighn, R. J., & Yu, S. L. (1996). Testing of Roadside Vegetation for Highway Runoff Pollutant Removal. *Transportation Research Record: Journal of the Transportation Research Board*, *1523*(1), 116–123. doi: 10.1177/0361198196152300114

Ke, C., Li, Z., Liang, Y., Tao, W., & Du, M. (2013). Impacts of chloride de-icing salt on bulk soils, fungi, and bacterial populations surrounding the plant rhizosphere. *Applied Soil Ecology*, *72*, 69–78. doi: 10.1016/j.apsoil.2013.06.003

Keller, L. P., Mccarthy, G. J., & Richardson, J. L. (1986). Mineralogy and Stability of Soil Evaporites in North Dakota1. *Soil Science Society of America Journal*, *50*(4), 1069. doi: 10.2136/sssaj1986.03615995005000040047x

Ketterings, Q., Reid, S., & Rao, R. (2007). *Agronomy Fact Sheets, Cation Exchange Capacity (CEC)*(pp. 1-2, 22). Cornell University Cooperative Extension.

Köppen, W., & Geiger, R. (1936). *Handbuch der Klimatologie*. Berlin: Verlag von Gebrüder Borntraeger.

Kutiel, P., Eden, E., & Zhevelev, Y. (2000). Effect of experimental trampling and off-road motorcycle traffic on soil and vegetation of stabilized coastal dunes, Israel. *Environmental Conservation*, *27*(1), 14–23. doi: 10.1017/s0376892900000035

Maas, E. V., & Grattan, S. R. (1999). Crop Yields as Affected by Salinity. *Agricultural Drainage Agronomy Monograph*. doi: 10.2134/agronmonogr38.c3

Naidu, R., & Rengasamy, P. (1993). Ion interactions and constraints to plant nutrition in Australian sodic soils. *Soil Research*, *31*(6), 801.

NDOT. 2016. Some Facts and Figures from the Nebraska Department of Roads. Lincoln, NE.

NDOT. 2017. Standard Specifications For Highway Construction. Lincoln, NE.

NDOT. 2019. NDOT Roadside Vegetation Establishment and Management. Lincoln, NE.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter analysis. In: D.L. Sparks, et a., editor, Methods of soil analysis, Part 3: Chemical methods. Book Ser. 5.3. SSSA, ASA, Madison, WI. p. 961–1010. doi:10.2136/sssabookser5.3.c34

Department of Environmental Quality, 2016. Authorization to Discharge Under the National Pollutant Discharge Elimination System (NPDES) General NPDES Permit Number NERI 60000 for Storm Water Discharges from Construction Sites to Waters of the State of Nebraska. Lincoln, NE.

NRCS, 2014. Soil Electrical Conductivity, Guide for Educators.

NRCS, 2019. Soil Bulk Density/Moisture/Aeration, Guide for Educators.

Petersen, S. L., Roundy, B. A., & Bryant, R. M. (2004). Revegetation Methods for High-Elevation Roadsides at Bryce Canyon National Park, Utah. *Restoration Ecology*, *12*(2), 248–257. doi: 10.1111/j.1061-2971.2004.00321.x

Qadir, M., Schubert, S., Ghafoor, A., & Murtaza, G. (2001). Amelioration strategies for sodic soils: a review. *Land Degradation & Development*, *12*(4), 357–386. doi: 10.1002/ldr.458

Raper, R. (2005). Agricultural traffic impacts on soil. *Journal of Terramechanics*, *42*(3-4), 259–280. doi: 10.1016/j.jterra.2004.10.010

Rengasamy, P., & Walters, L. (1994). *Introduction to soil sodicity* . Cooperative Research Centre for Soil & Land Management.

Rickard, C., Mclachlan, A., & Kerley, G. (1994). The effects of vehicular and pedestrian traffic on dune vegetation in South Africa. *Ocean & Coastal Management*, *23*(3), 225–247. doi: 10.1016/0964-5691(94)90021-3

Ries, L., Debinski, D. M., & Wieland, M. L. (2001). Conservation Value of Roadside Prairie Restoration to Butterfly Communities. *Conservation Biology*, *15*(2), 401–411.

Rodriguez, P., Torrecillas, A., Morales, M., Ortuno, M., & Sanchezblanco, M. (2005). Effects of NaCl salinity and water stress on growth and leaf water relations of plants. *Environmental and Experimental Botany*, *53*(2), 113–123. doi: 10.1016/j.envexpbot.2004.03.005

Rotholz, E., & Mandelik, Y. (2013). Roadside habitats: effects on diversity and composition of plant, arthropod, and small mammal communities. *Biodiversity and Conservation*, *22*(4), 1017–1031. doi: 10.1007/s10531-013-0465-9

Rutter, A. J., & Thompson, J. R. (1986). The Salinity of Motorway Soils. III. Simulation of the Effects of Salt Usage and Rainfall on Sodium and Chloride Concentrations in the Soil of Central Reserves. *The Journal of Applied Ecology*, *23*(1), 281. doi: 10.2307/2403097

SAS Institute. 2012. The SAS system for Windows. Release 9.4. SAS Inst., Cary, NC

Seeling, B.D. (2000). *Salinity and Sodicity in North Dakota Soils*. North Dakota State University Extension Service Publication.

Skinner, A. K., Lunt, I. D., Spooner, P., & Mcintyre, S. (2009). The effect of soil compaction on germination and early growth ofEucalyptus albensand an exotic annual grass. *Austral Ecology*, *34*(6), 698–704. doi: 10.1111/j.1442-9993.2009.01977.x

So, H., & Aylmore, L. (1993). How do sodic soils behave - the effects of sodicity on soil physical behavior. *Soil Research*, *31*(6), 761. doi: 10.1071/sr9930761

Soil Science Division Staff. 2017. Soil survey manual. C. Ditzler, K. Scheffe, and H.C. Monger (eds.). USDA Handbook 18. Government Printing Office, Washington, D.C.

Sumner, M.E., and W.P. Miller. 1996. Cation exchange capacity and exchange coefficients. In: D.L. Sparks, et a., editor, Methods of soil analysis, Part 3: Chemical methods. Book Ser. 5.3. SSSA, ASA, Madison, WI. p. 1201– 1229. doi:10.2136/sssabookser5.3.c40

Sveistrup, T. E., & Haraldsen, T. K. (1997). Effects of soil compaction on root development of perennial grass leys in northern Norway. *Grass and Forage Science*, *52*(4), 381–387. doi: 10.1111/j.1365-2494.1997.tb02370.x

Thompson, J. R., Rutter, A. J., & Ridout, P. S. (1986). The Salinity of Motorway Soils. I. Variation in Time and Between Regions in the Salinity of Soils on Central Reserves. *The Journal of Applied Ecology*, *23*(1), 251. doi: 10.2307/2403095

Trahan, N. A., & Peterson, C. M. (2017). *Factors Impacting The Health Of Roadside Vegetation*. *Factors Impacting The Health of Roadside Vegetation*. Colorado Department of Transportation Research Branch.

Unger, P. W., & Kaspar, T. C. (1994). Soil Compaction and Root Growth: A Review. *Agronomy Journal*, *86*(5), 759. doi: 10.2134/agronj1994.00021962008600050004x

Wang, L., Seki, K., Miyazaki, T., & Ishihama, Y. (2009). The causes of soil alkalinization in the Songnen Plain of Northeast China. *Paddy and Water Environment*, *7*(3), 259–270. doi: 10.1007/s10333-009-0166-x

White, P. J., & Broadley, M. R. (2001). Chloride in Soils and its Uptake and Movement within the Plant: A Review. *Annals of Botany*, *88*(6), 967–988. doi: 10.1006/anbo.2001.1540

Zaman, M., Shahid, S. A., & Heng, L. (2018). *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*. Cham: Springer International Publishing.

Zhang, Q., Rue, K., & Wang, S. (2012). Salinity Effect on Seed Germination and Growth of Two Warm-season Native Grass Species. *HortScience*, *47*(4), 527–530. doi: 10.21273/hortsci.47.4.527

Zhu, J. (2001). Plant Salt Stress. *Encyclopedia of Life Sciences*. doi: 10.1038/npg.els.0001300

TABLES

Table 1

The percent of the total sites, from the Panhandle, Southcentral and Southeast regions, for each vegetation category observed in May of 2019.

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%

Table 2

The percent of the total sites, from the Panhandle, Southcentral and Southeast regions, for each soil category based off 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%

FIGURES

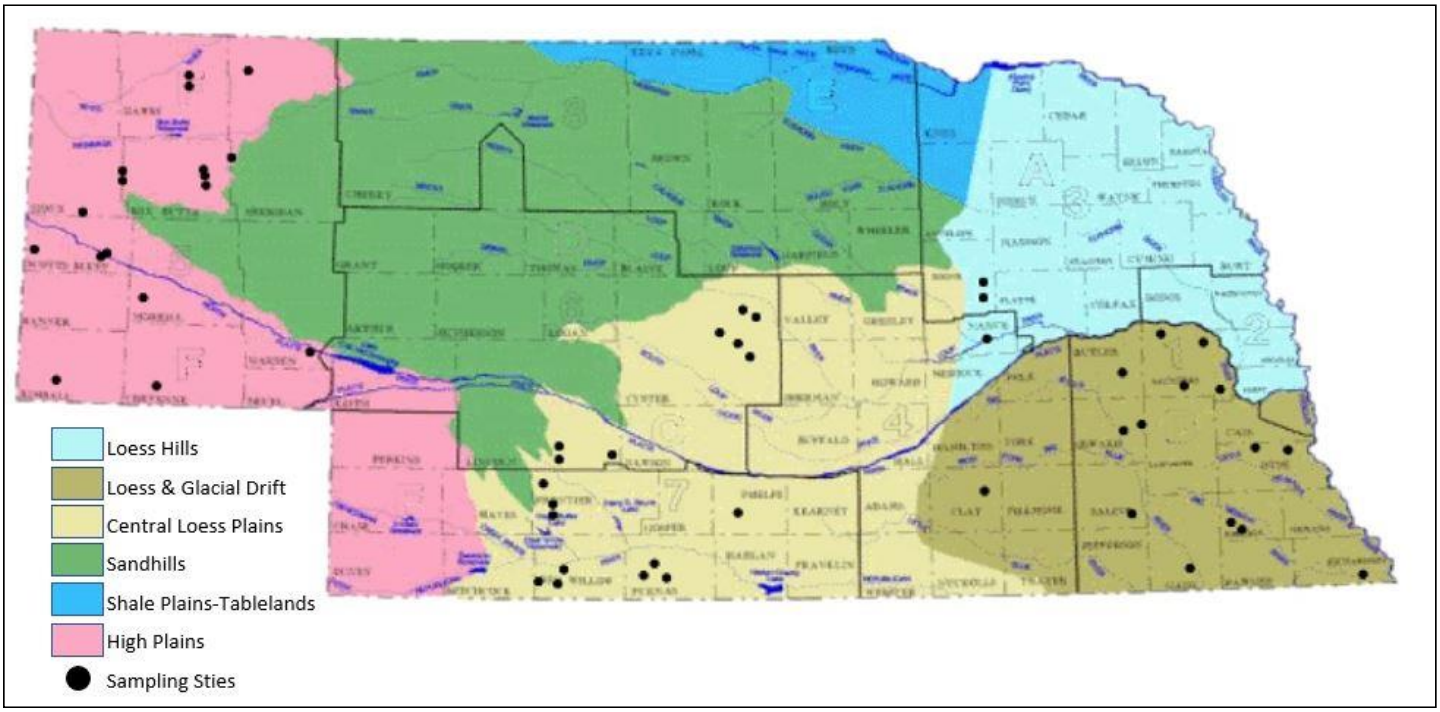


Fig. 1. Map shows the ecoregions that divide the state of Nebraska, with sampling locations in each region shown with black dots.

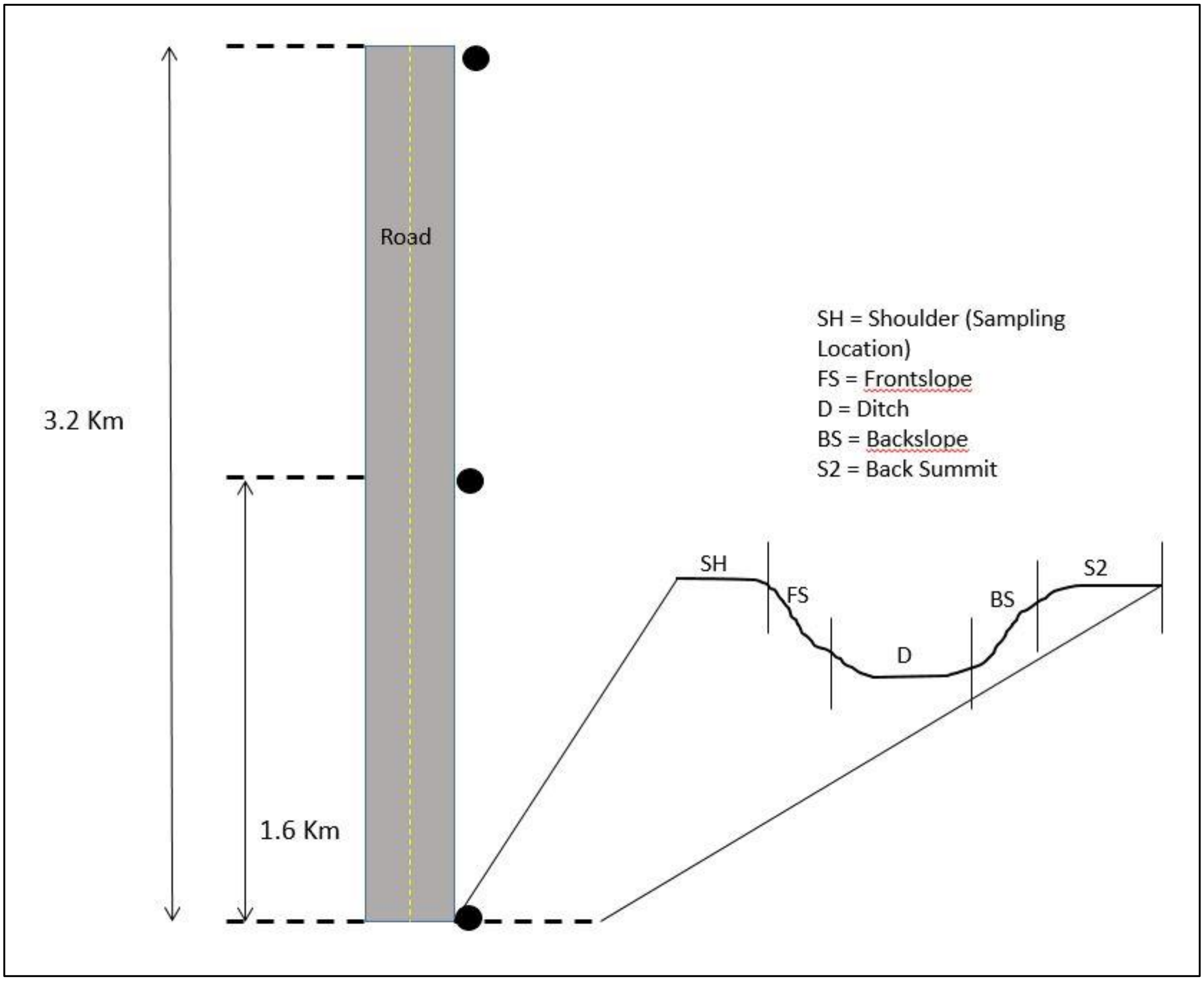
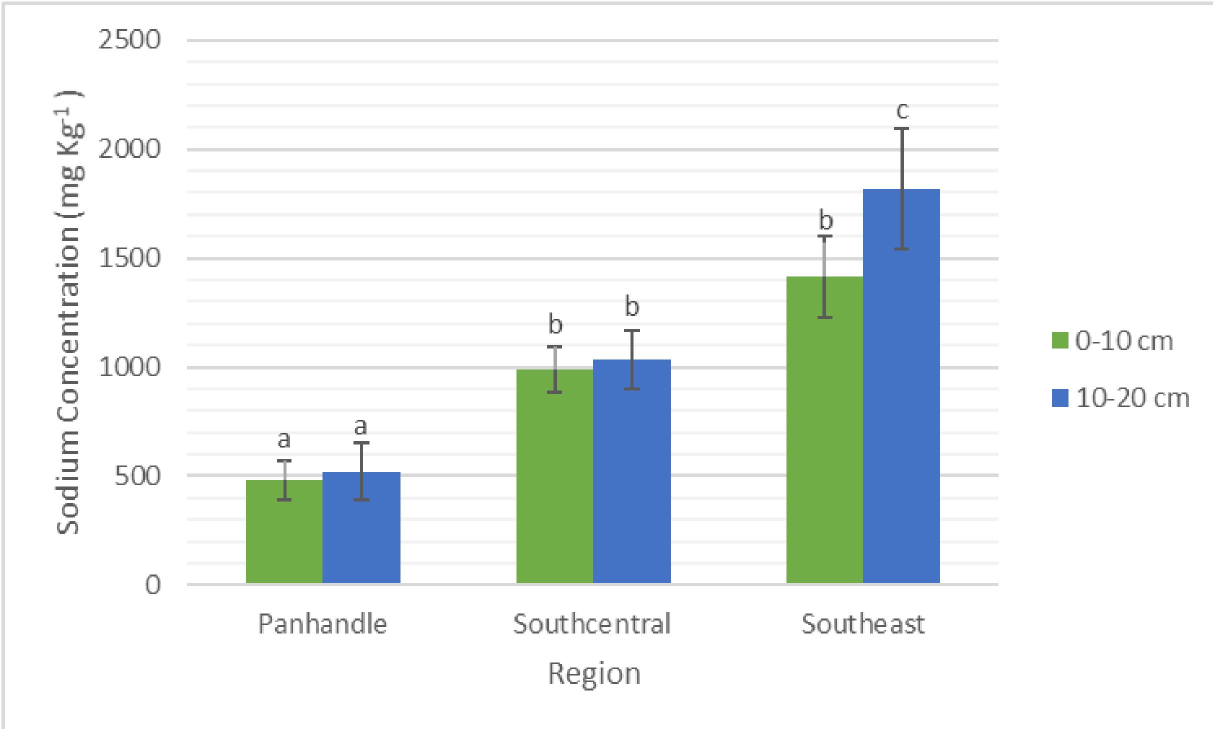


Fig. 2. Sampling was done in the shoulder position, 30 cm off the pavement. Three samples were collected in a 3.2 km stretch of highway and were 1.6 km apart.

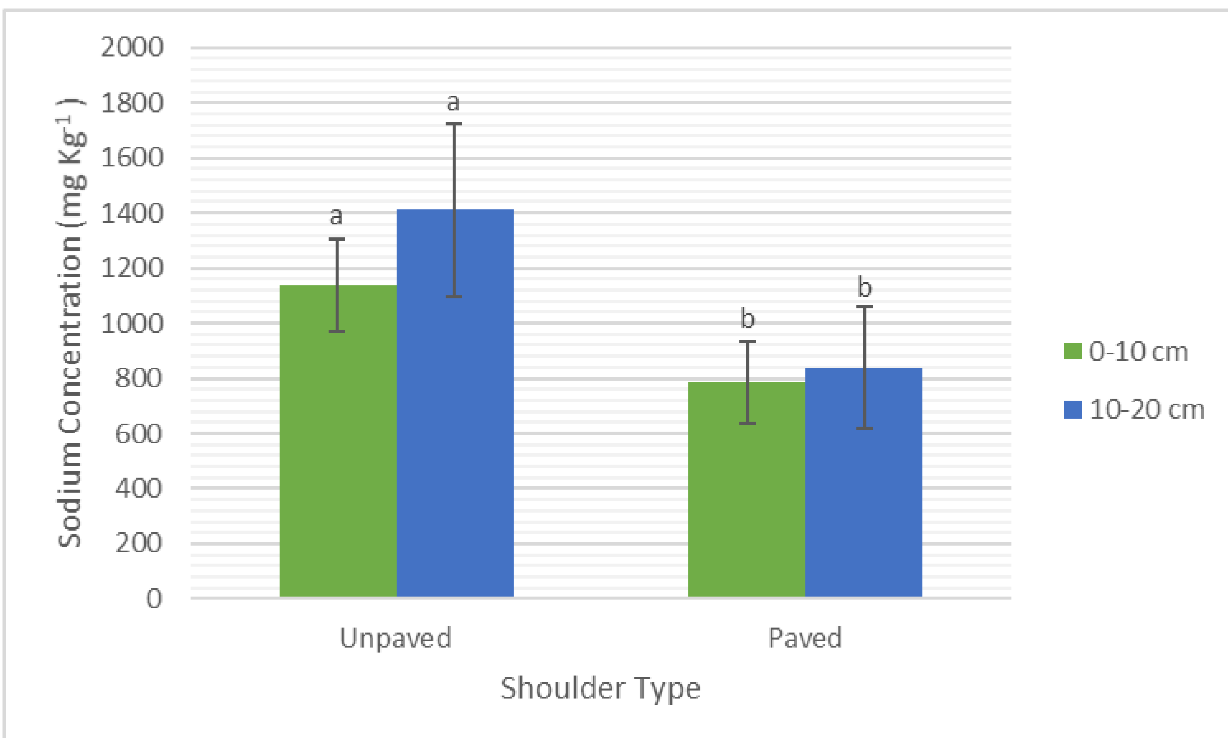
Fig. 3. Shows the vegetation cover categories. (a) Bare ground category (>70%). (b) Annual weed category (>70%). (c) Perennial vegetation category (>50%). (d) Bare ground, annual weed mix (~50-50%).

(a)



2500
2000
1500
1000
500
0
Sodium Concentration (mg Kg-1)
a
a
b
b
b
c
Panhandle
Southcentral
Southeast
Region
0-10 cm
10-20 cm

(b)



2000
1800
1600
1400
1200
1000
800
600
400
200
0
Sodium Concentration (mg Kg-1)
a
a
b
b
Unpaved
Paved
Shoulder Type
0-10 cm
10-20 cm

(c)

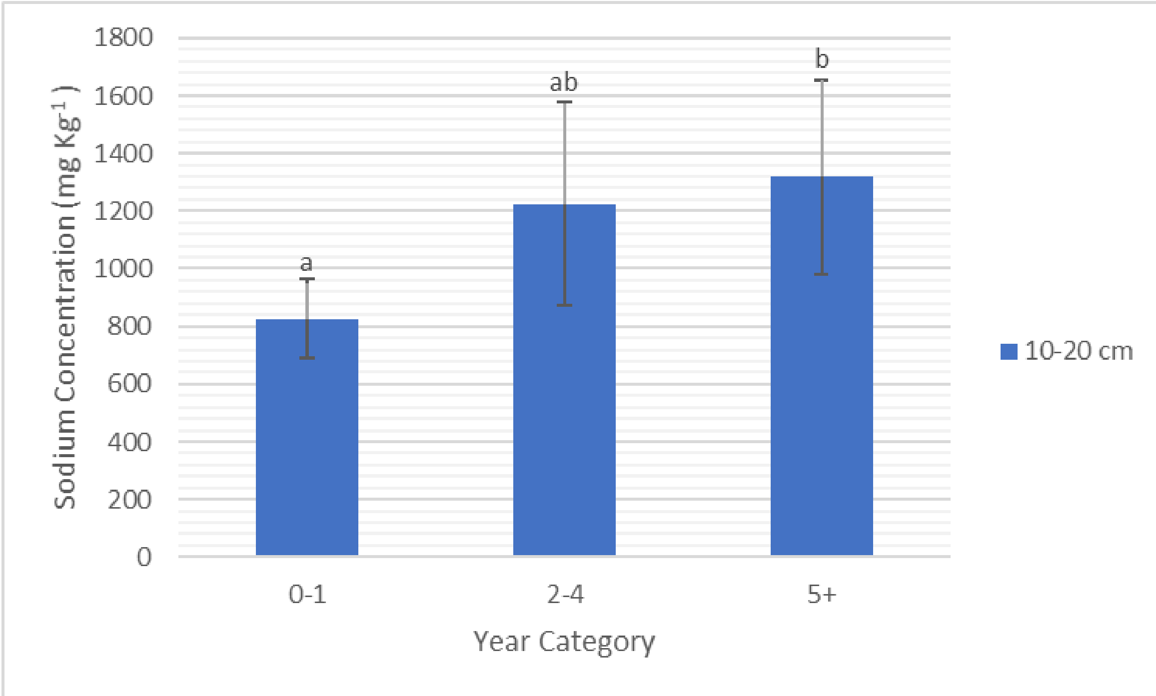
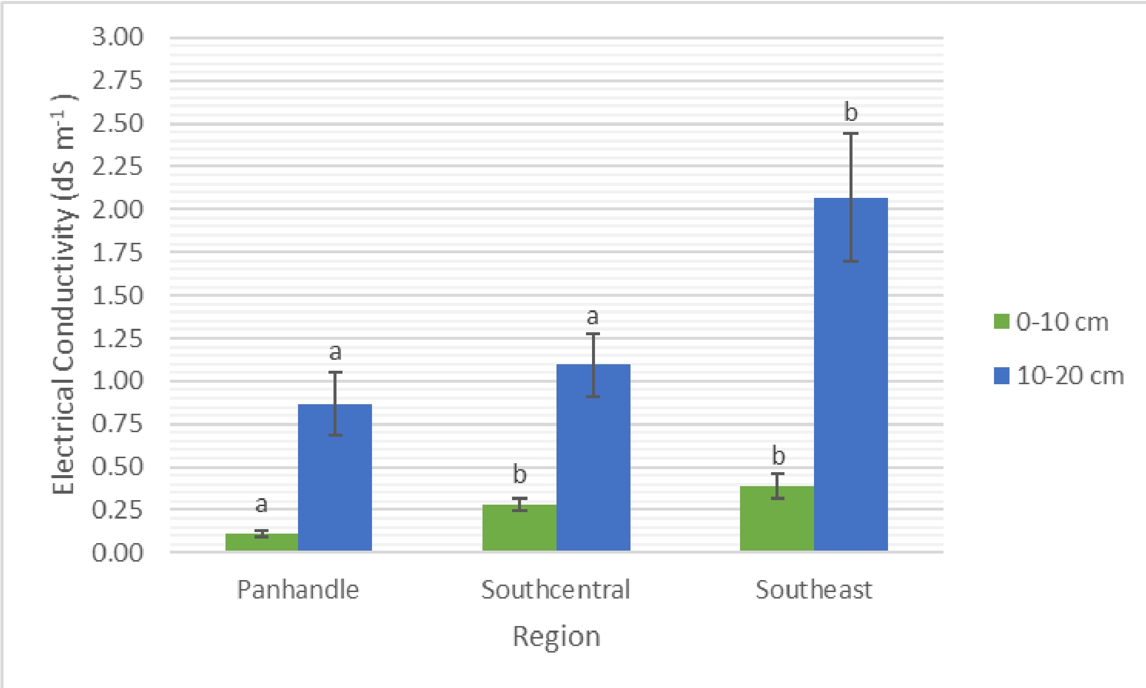


Fig. 4. Differences of sodium concentrations by region, shoulder type and year. (a) The difference in concentration levels by region with the Panhandle region having the lower concentrations at both depth intervals. (b) The difference by shoulder type with unpaved shoulders having higher concentrations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

(a)



(b)

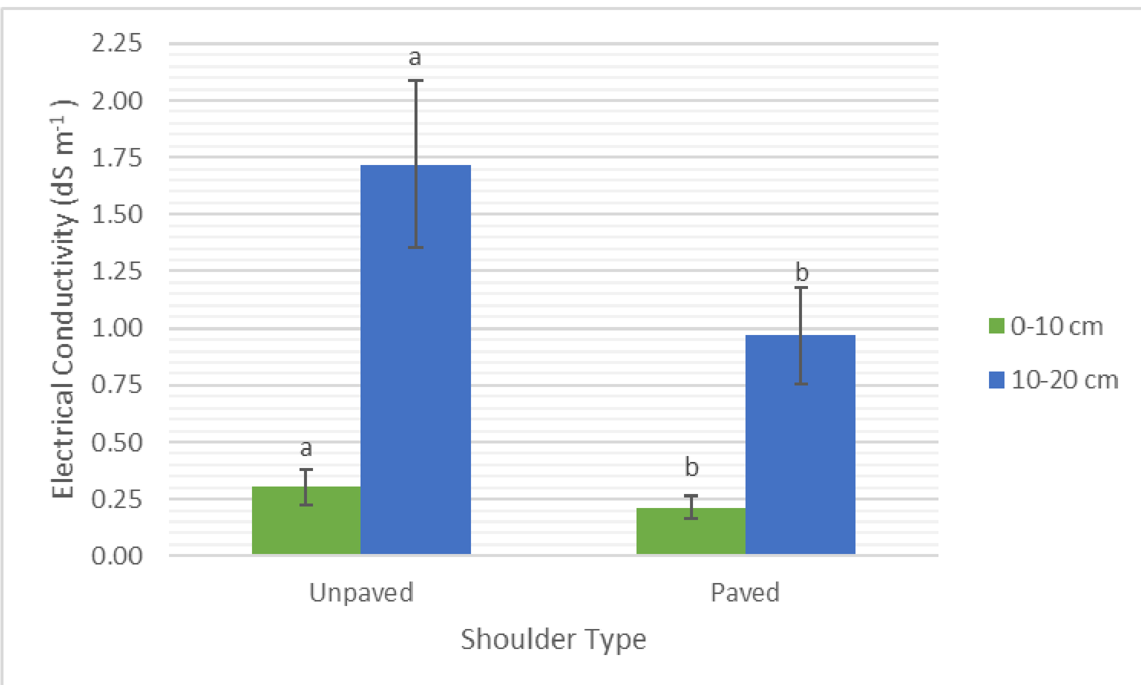


Fig. 5. Differences of electrical conductivity (EC) by region and shoulder type. (a) The differences by region with the Panhandle region having the lowest values at both depth intervals. (b) The difference by shoulder type with unpaved shoulders having higher values at both depth intervals.

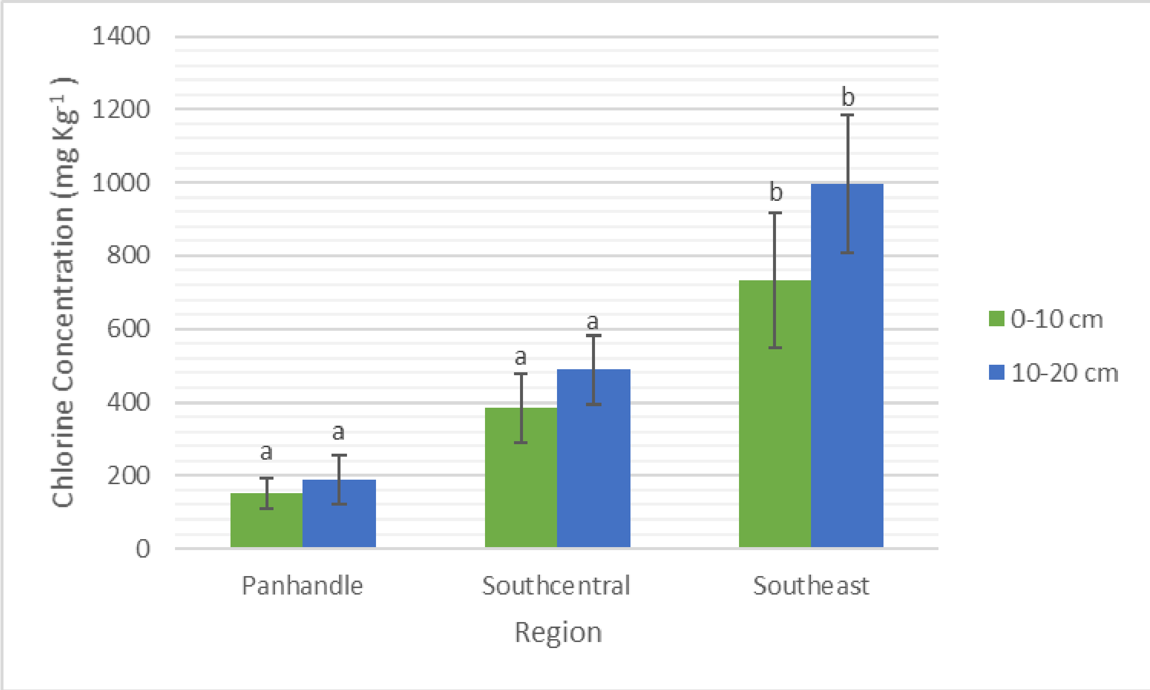


Fig. 6. Chloride concentration differences by region. Showed a similar west to east gradient like that of the sodium concentration graph, with Southeast region being the highest concentration.

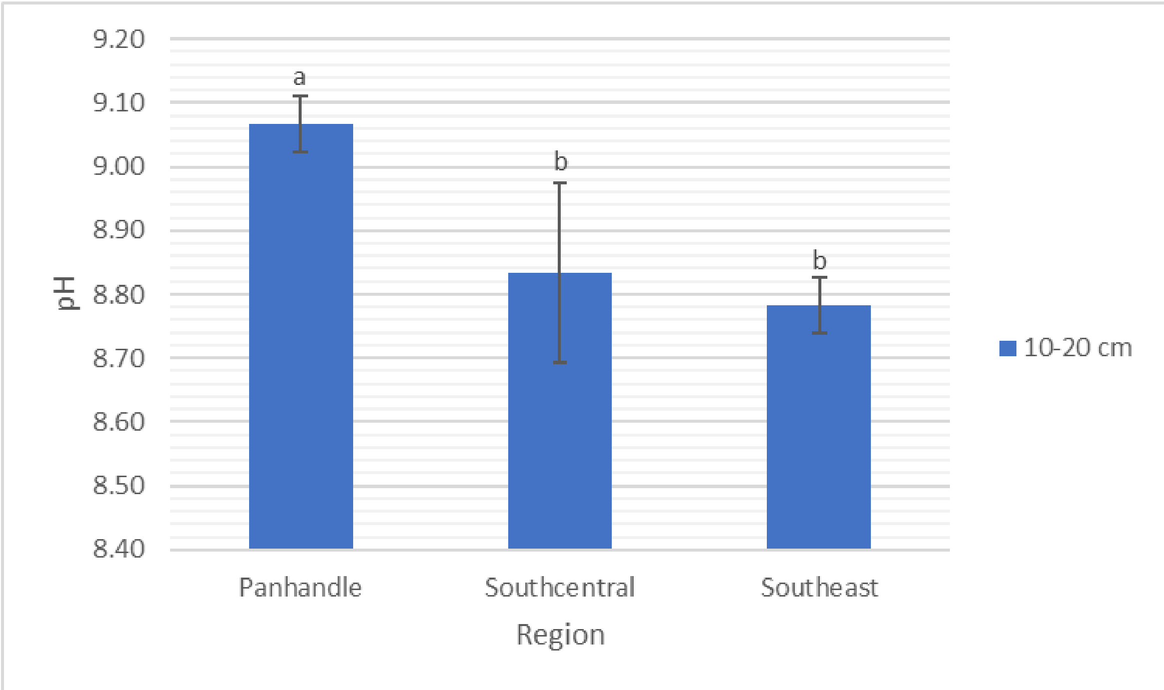
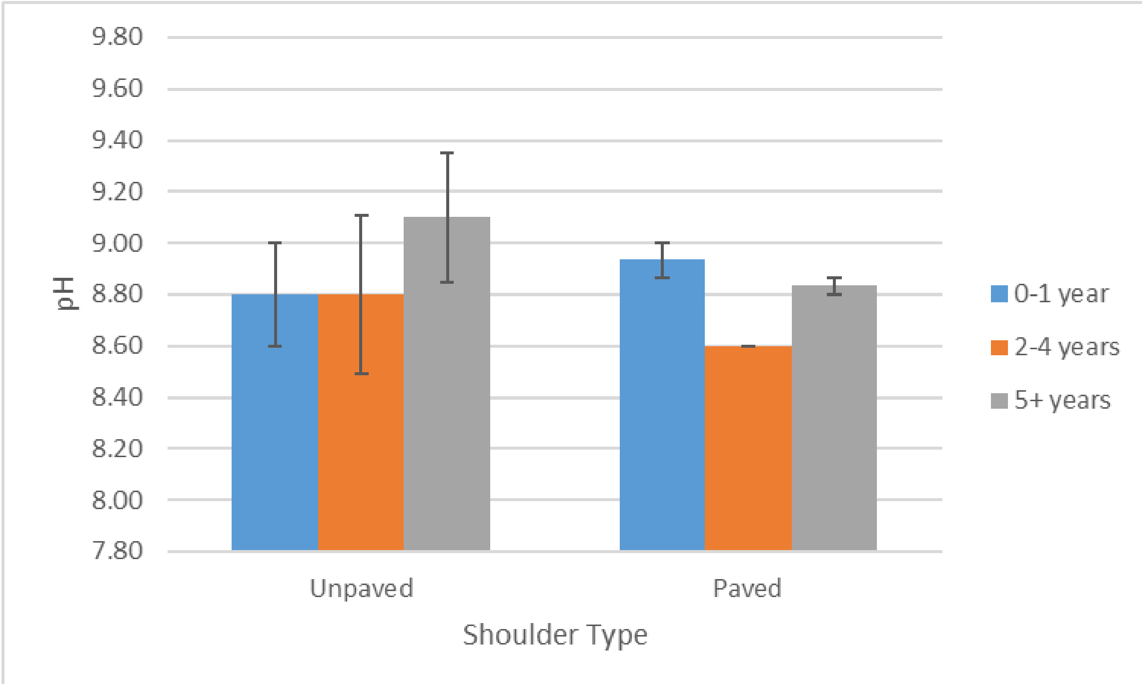
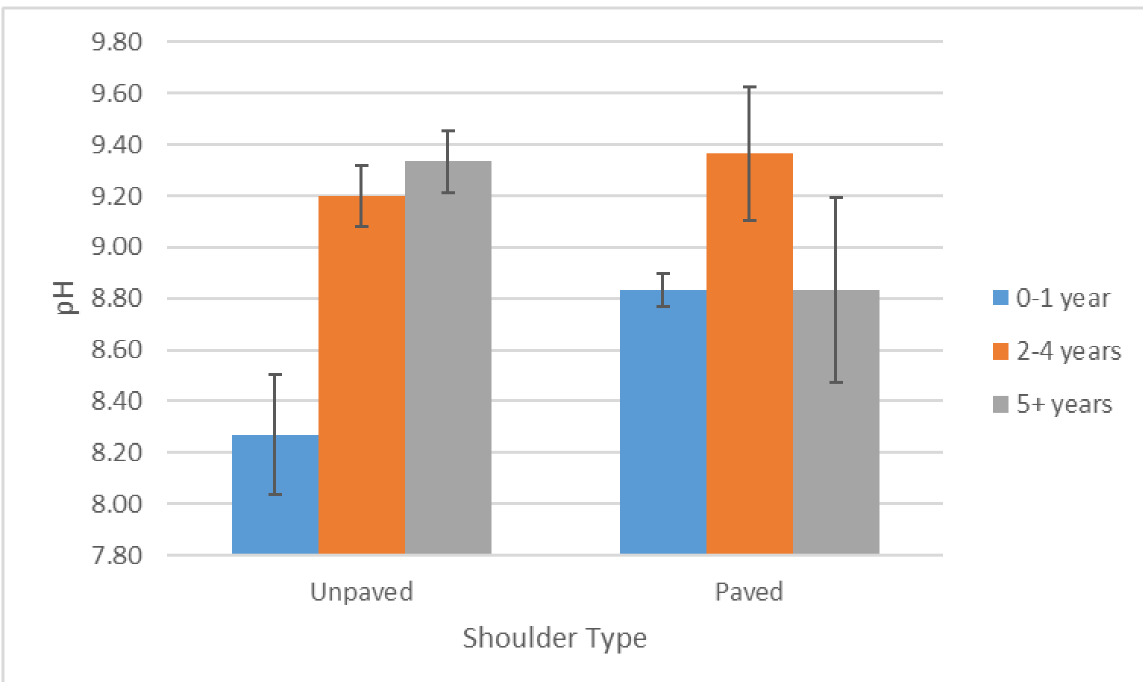


Fig. 7. Regional differences of the pH at 10-20 cm depth, with Panhandle having a higher pH.

(a)


9.80
9.60
9.40
9.20
9.00
8.80
8.60
8.40
8.20
8.00
7.80
pH
Unpaved
Paved
Shoulder Type
0-1 year
2-4 years
5+ years

(b)


9.80
9.60
9.40
9.20
9.00
8.80
8.60
8.40
8.20
8.00
7.80
pH
Unpaved
Paved
Shoulder Type
0-1 year
2-4 years
5+ years

(c)

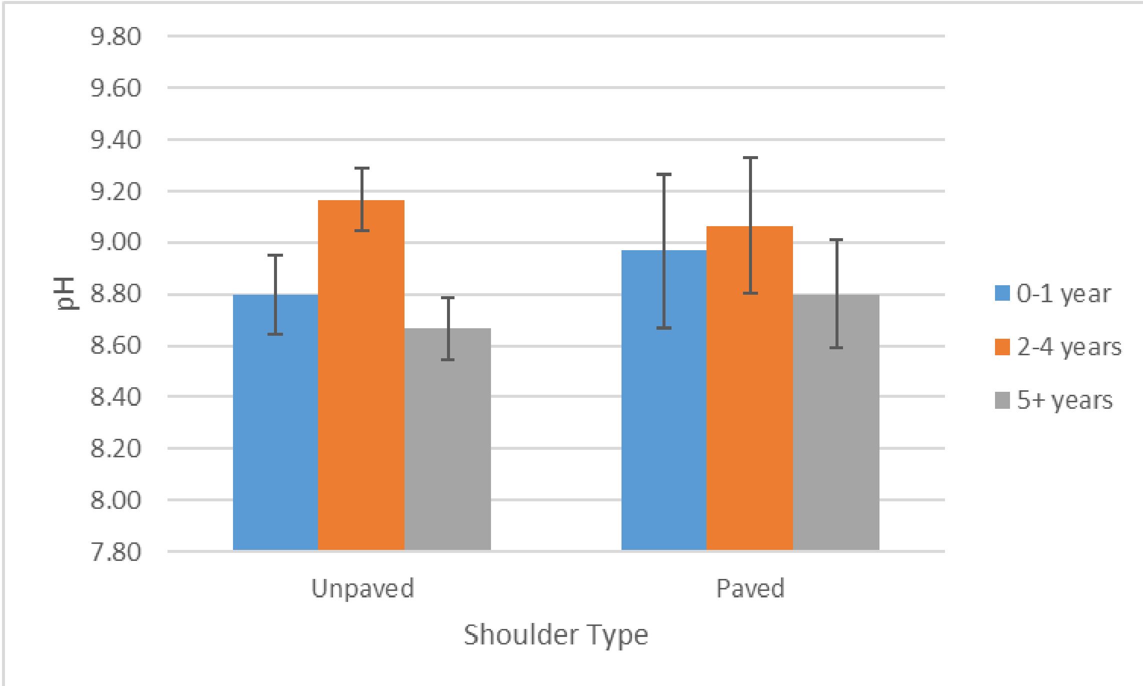


Fig. 8. The year x shoulder x region interaction. (a) The interaction within the Panhandle region. (b) The interaction within the Southcentral region. (c) The interaction within the Southeast region.

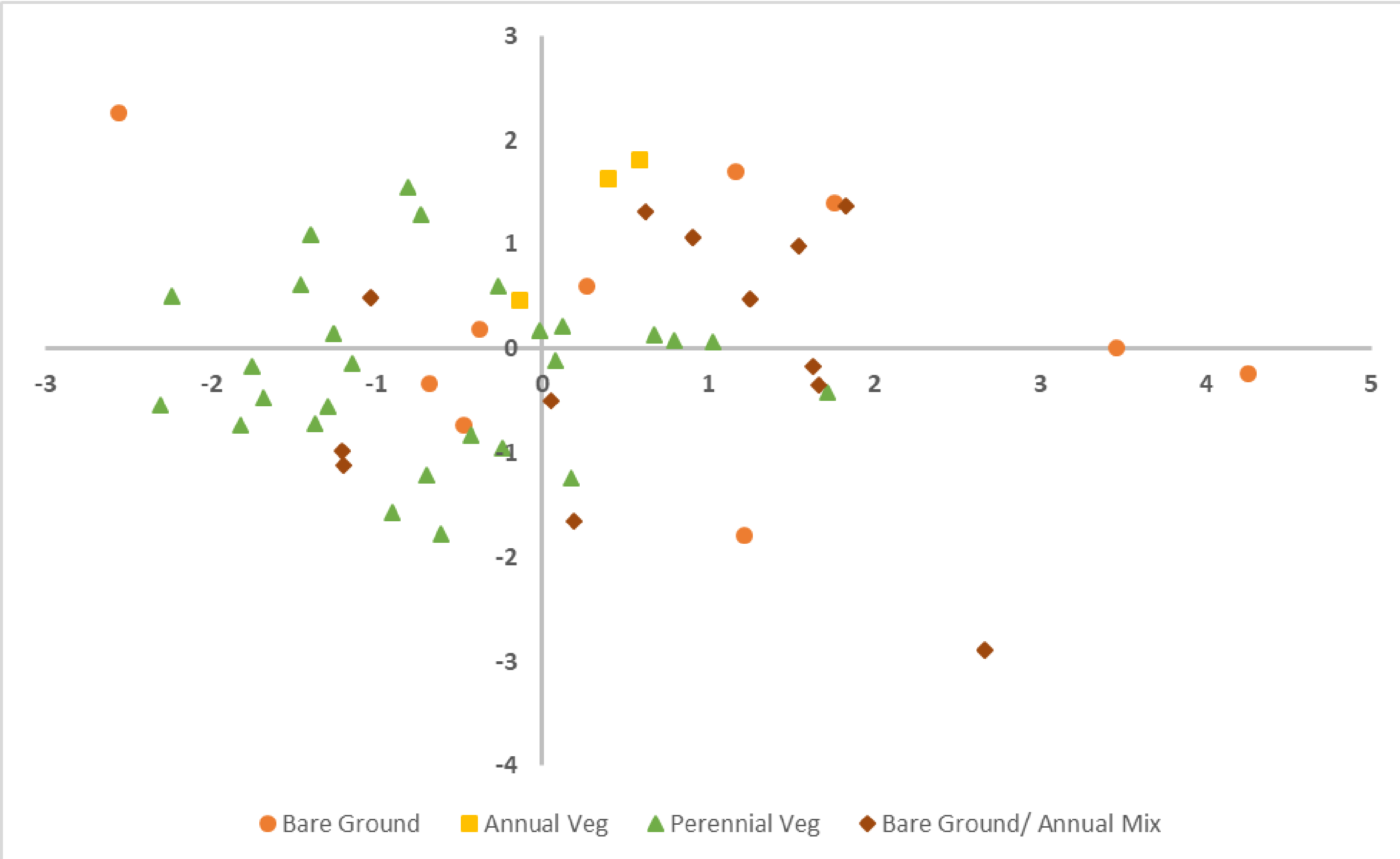


Fig. 9. The different colored shapes represent the vegetation category of each of the 53 sites. With no significant groupings of the categories, no soil property or combination is thought to be a driving factor or vegetation cover.

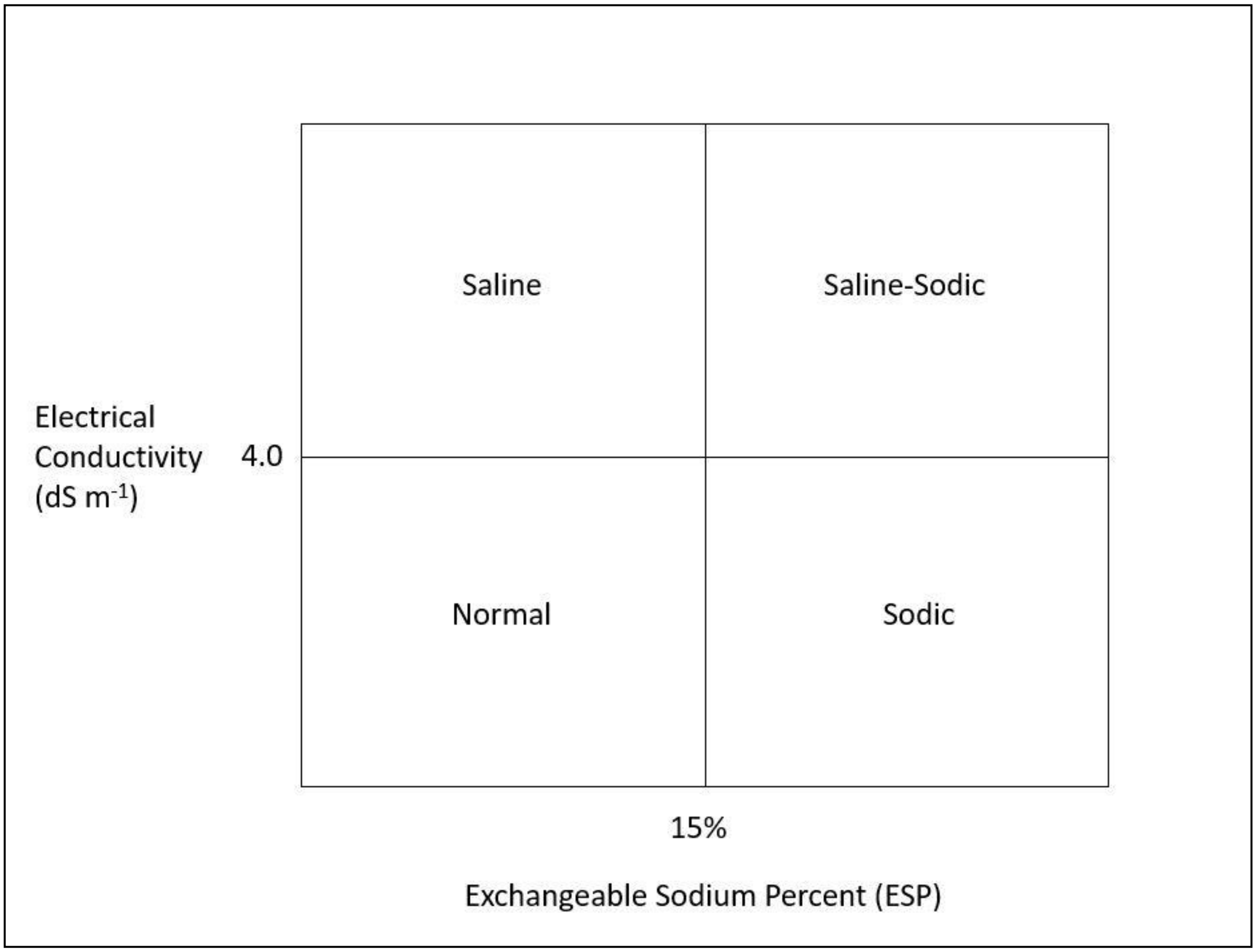


Fig. 10. Showing the soil categories of saline and sodic with the respected variable used for determining classification.

APPENDIX

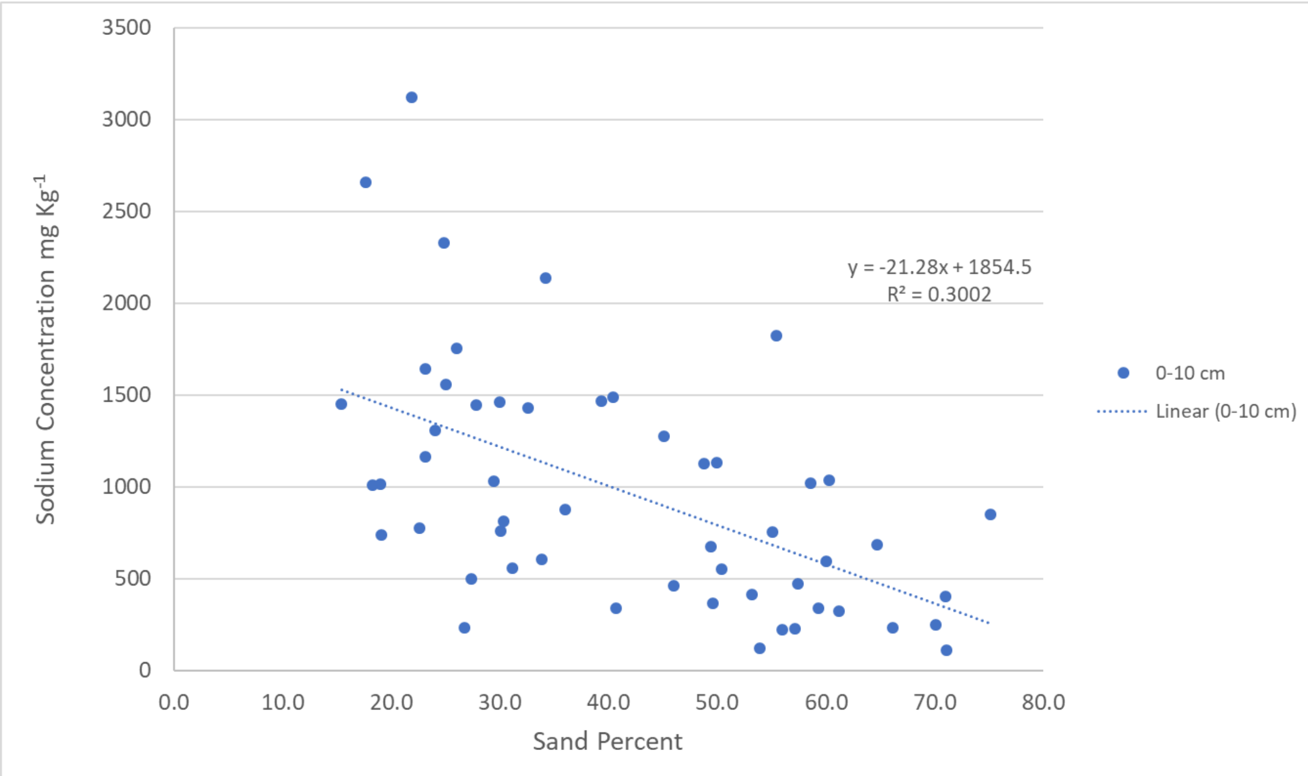


Fig. 1. Shows the percent sand to sodium concentration for each sample taken. There was only a slight negative correlation.

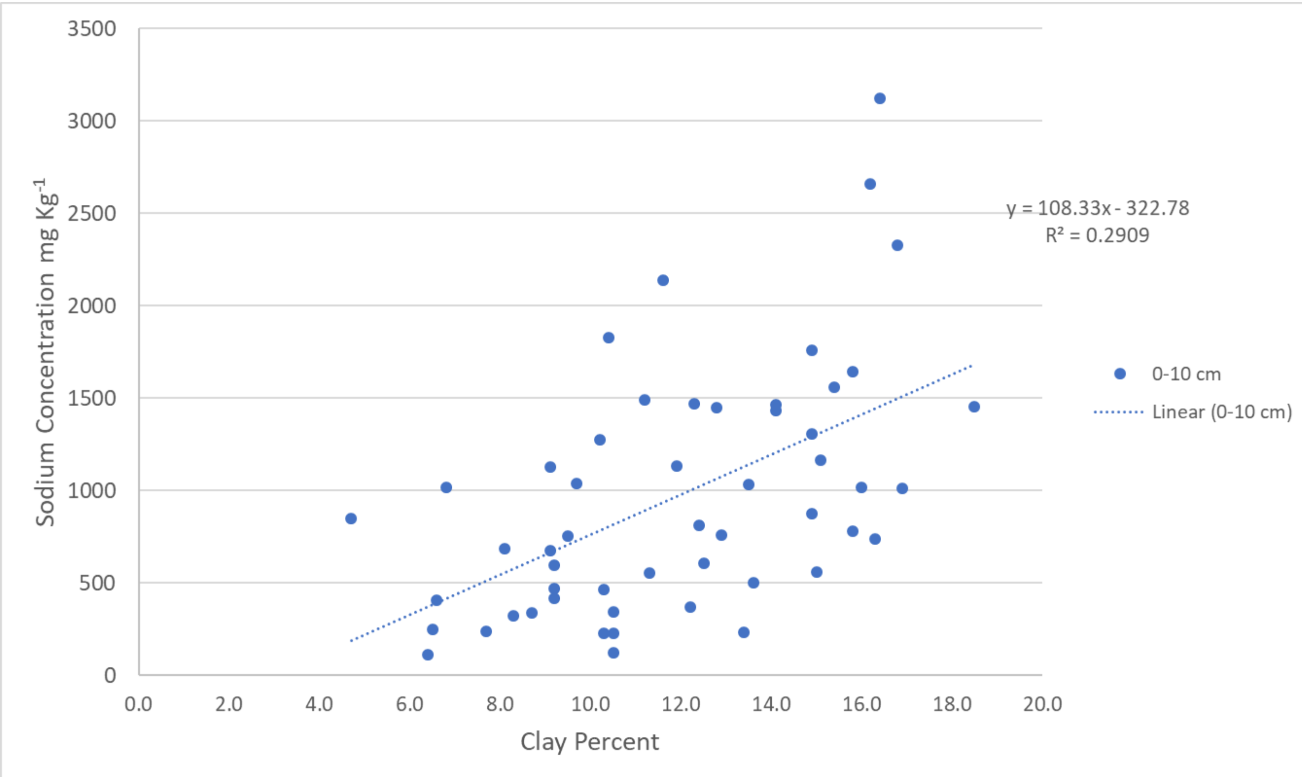


Fig. 2. Shows the percent clay to sodium concentration for each sample taken. There was only a slight positive correlation.

Table 1.

Description of highways selected for soil sampling from the Panhandle, Southcentral, and Southeast regions of Nebraska with the date when each construction project was seeded and closed

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	113-111	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

SAS code used for analyses was as follows

Data Input

```
data;
Input region shoulder year site depth BD Gravel pH EC Na Cl;
datalines;
```

Used to create an ANOVA for each variable tested

```
proc mixed method = type1;
Class region shoulder year depth site;
Model = Region shoulder year depth shoulder*year year*region shoulder*region year*shoulder*region;
Random site(region);
lsmeans region shoulder year depth shoulder*year year*region shoulder*region
year*shoulder*region/pdiff;
run;
```

Used to create the PCA

```
proc princomp out=griz;
var BD pH Na EC;
run;
proc print;
run;

proc mixed method = type1;
Class region shoulder year site;
Model prin1 = Region shoulder year shoulder*year year*region shoulder*region year*shoulder*region;
Random site(region);
lsmeans region shoulder year shoulder*year year*region shoulder*region year*shoulder*region/pdiff;
run;

proc mixed method = type1;
Class region shoulder year site;
Model prin2 = Region shoulder year shoulder*year year*region shoulder*region year*shoulder*region;
Random site(region);
lsmeans region shoulder year shoulder*year year*region shoulder*region year*shoulder*region/pdiff;
run;

proc princomp data=griz out=griz1;
var BD Gravel Na pH EC;
```

```
run;
proc plot data=griz1; plot prin2*prin1=veg;
run;

proc glm data= griz1;
class veg;
model BD Gravel Na pH EC = veg;
lsmeans veg;
run;
```

Used to create the PCA table

```
proc plot data=griz1; plot prin2*prin1=region;
run;
```