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Soil Structure and Chemistries of Brine-Impacted Soils in West Texas

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Abstract

The goal of this research is to use geoinformatics, geochemistry, hydrogeology, and soil chemistry to form a multidisciplinary approach aimed at remediating brine impacted soils. The primary research location is a 14-acre "kill zone" located on a private ranch approximately 14 kilometers south of San Angelo, Tom Green County, Texas. The Natural Resources Conservation Service (NRCS) classifies the site soils as part of the Angelo Series, a clay loam derived from limestone. A Geospatial Information System for 3-D soil chemistry modeling which includes measuring for total alkalinity, extractable calcium, chloride, total copper, potassium, magnesium, sodium, total phosphorus, nitrate, pH, SAR, and total nitrogen was compiled from soil sampling over 2015. Average sodium levels exceed 2500 mg/kg, and average chloride levels exceed 5500 mg/kg. This excess of sodium classifies the soils not only as saline soils, but also as a sodic soil. Chemistry data was analyzed by creating ternary diagrams allowing for soil classifications. All data collected are stored in a ArcGIS database for data management, project planning, and various models. Lithologic data manipulated in ArcGIS is transferred to ArcSCENE to create 3-D models of the subsurface. Techniques for remediation that are being investigated include: bioremediation with halophytes, physical soil ripping and furrowing, and using various soil amendments including magnesium sulfate, gypsum, and compost. This research is ongoing and further exploration regarding soil chemistry and forage quality will be analyzed 2016.

Methodology

- Collect and analyze geospatial data using GPS
- Collect soil samples (top 6")
- Process soil data in Geochemist Workbench
- Collect soil samples (top 6") with the YSI multiprobe to calculate electrical conductivity (EC) by using $EC_{1:5}$ test
- Determine if soils are sodic, saline, or both by calculating the sodium adsorption ratio (SAR), the exchangeable sodium percentage (ESP), and interpreting the electrical conductivity (EC)

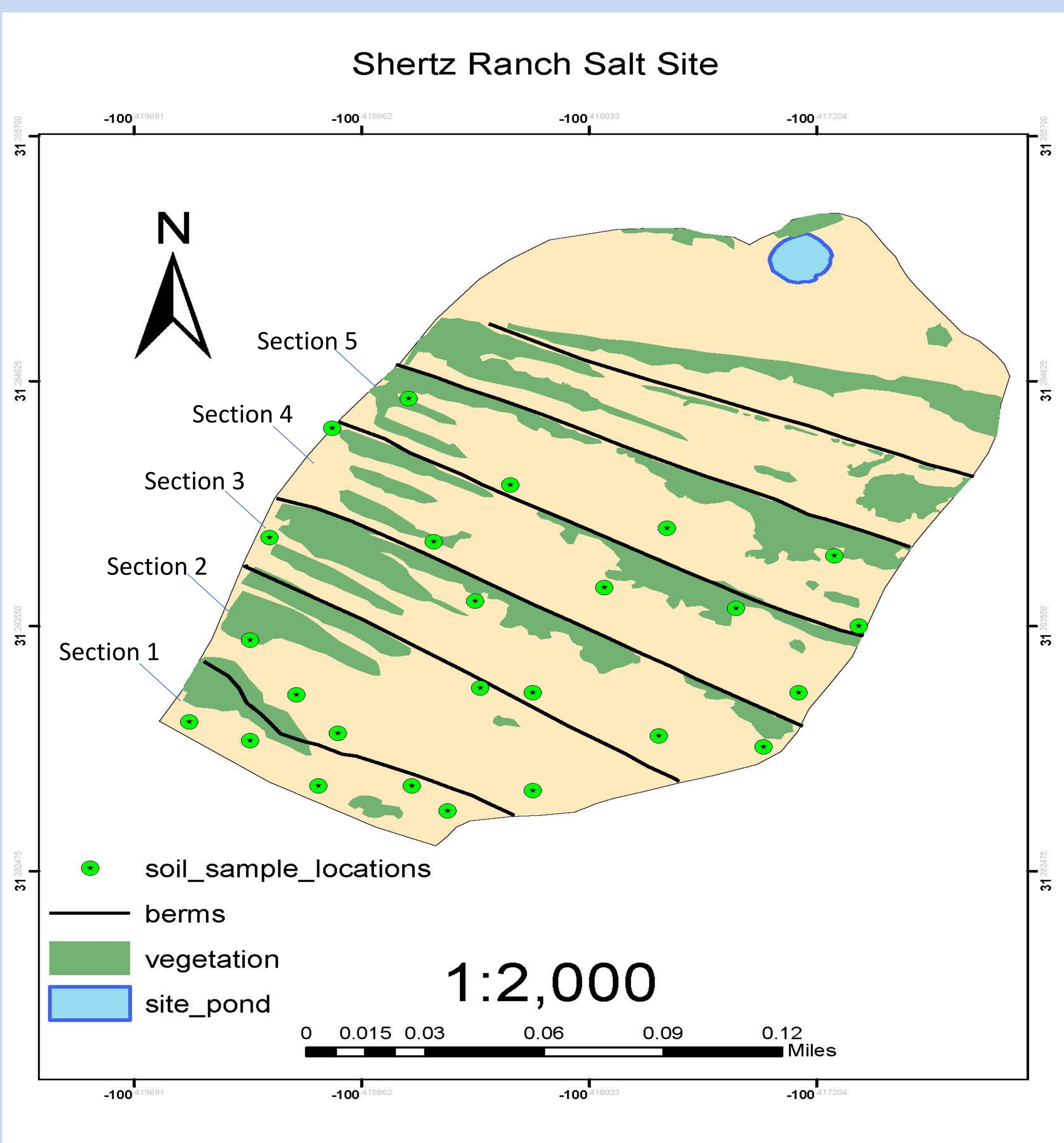

Figure 2: Map of Site Showing Soil Sample Locations

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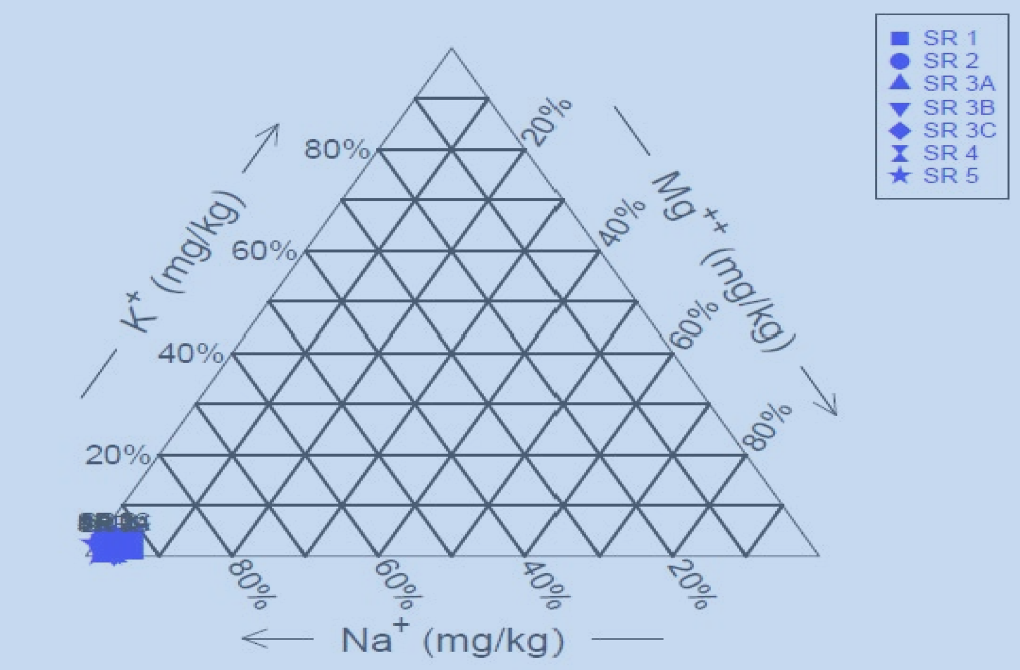

Figure 1a: Ternary Plot Showing Low Percentages of K^+ and Mg^{2+} Relative to Na^+

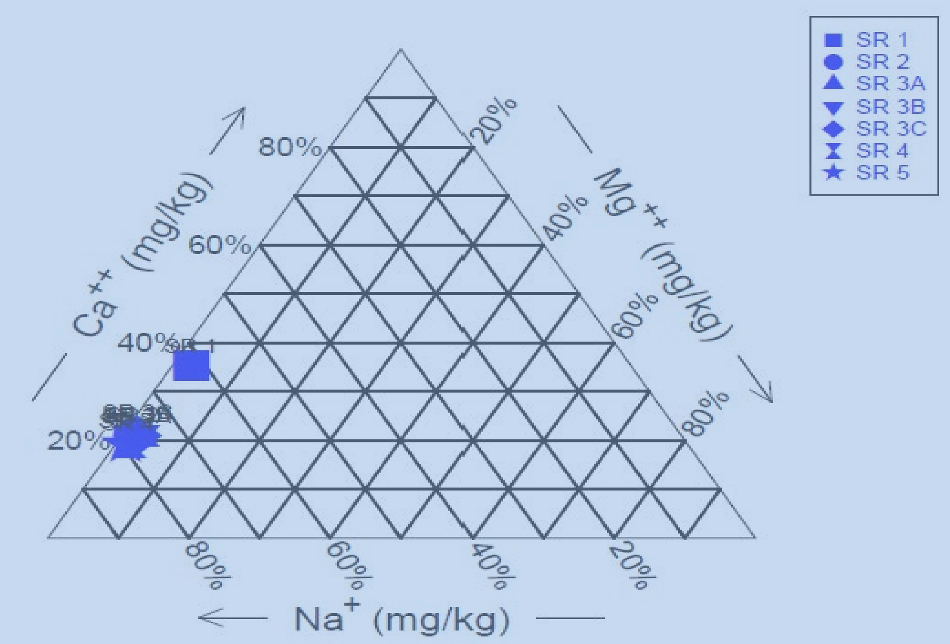

Figure 1b: Ternary Diagram Showing Low Percentages of Ca^{2+} and Mg^{2+} Relative to Na^+

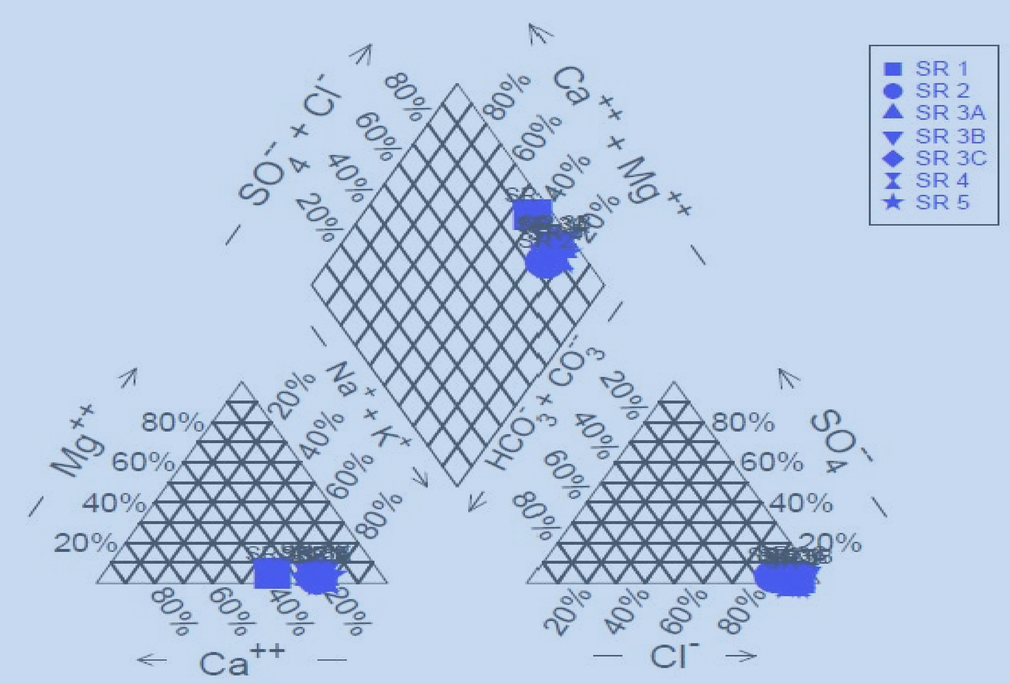

Figure 1c: Piper Plot Showing Chemistry Clustering of all 5 Sections.

Site Soil Structure

Due to the excess amount of salts found on-site, the structure of the soil has been adversely affected. A salt crust is formed on the surface of the site. This crust impedes water infiltration. Without proper infiltration, the soils dry out and are allowed to become severely compacted. A penetrometer measure the soil pressure at >500 psi, where plants cannot push their roots past 300 psi.

Because the soils ESP is >70, the soils can become dispersed. This dispersion causes the clay particles to create impermeable layers that can further impede water infiltration. Tom Green County, Texas averages 21.25" of rainfall per year, and an average yearly pan evaporation rate of 71.5".

This difference between precipitation and evaporation allows for low soil moisture content. The high rate of evaporation creates mud cracks along the surface of the site. These mud cracks should allow for infiltration of water into the soil, but the clay layers formed from soil dispersion retard infiltration.

Site Soil Chemistries

Ions necessary for plant growth

- Nitrogen (N)
- Potassium (K^+)
- Calcium (Ca^{2+})
- Magnesium (Mg^{2+})
- Phosphorous (P)
- Sulfur (S)
- Chlorine (Cl^-)
- Iron (Fe)
- Boron (B)
- Manganese (Mn^{2+})
- Zinc (Zn)
- Copper (Cu)
- Molybdenum (Mo)
- Nickel (Ni^{2+})

Ions tested for and necessary concentrations

- Ca^{2+}: 5000 mg/kg
- Cl^- : 100 – 2800 mg/kg
- Total Cu: 6 – 50 mg/kg
- K^+: 300 – 800 mg/kg
- Mg^{2+}: 2000mg/kg
- Na^+: 230 mg/kg
- No_3^-: 25 – 30 mg/kg
- P: 2000 mg/kg
- Total alkalinity (as $CaCO_3$)
- pH
- SAR

Average values in site soils

- Ca^{2+}: 857.9 mg/kg
- Cl^- : 6085.7 mg/kg
- Total Cu: 5.28 mg/kg
- K^+: 63.2 mg/kg
- Mg^{2+}: 77.0 mg/kg
- Na^+: 2904.3 mg/kg
- No_3^- : 89.7 mg/kg
- P: 219.7 mg/kg
- Alkalinity: 771.4 mg/kg
- pH: 7.6
- SAR: 25.9

Field Testing and In House Calculations

We conducted an $EC_{1:5}$ field test with a YSI multiprobe in order to determine the electrical conductivity of the soils. By determining the electrical conductivity, we are able to determine the level of salinity.

- **Table 2** shows the conversion from $EC_{1:5}$ to EC_{se}
- EC_{se} is equivalent to the EC of a saturated extract (method used to calculated EC in labs)
- Any value over 4 dS/m is considered saline
- Sections 1, 2, 4, and 5 exhibit saline electrical conductivities (**Table 2**)
- Section 3 has an EC_{se} of 3.12 dS/m (**Figure 3** shows possible solution)

We calculated SAR and ESP based on concentrations of ions found by the soil lab. The ESP and SAR are two ways to determine the sodicity of soils. Sodic soils have degraded soil structure and low relative Mg^{2+}, Ca^{2+}, and K^+ concentrations.

- Lab calculated concentrations in mg/kg
- SAR and ESP require units of meq/kg and meq/100g, respectively
- Conversion from mg/kg to meq/kg require the inverse of the equivalent weights of the desired ions
- Equation 1 shows the calculation for ESP. Average ESP over the entire site is 71.3%. Sodic soils are classified as anything with an ESP >15%
- Equation 2 shows the calculation for SAR. Average SAR that we calculated for the entire site was 25.5. This calculated number is a 1.5% difference than the lab calculation. Sodic soils are classified as having an SAR >5.

Figure 3: Water Pooling due to Berms in Section 3

Figure 4: Aerial Photo Showing Site and Lack of Vegetation

Figure 5: Photo Showing Salt Crust, Mudcracks, and Erosion

Tables and Equations

Table 1: Conversion from mg/kg to meq/kg and meq/100g

Ion	mg/kg	Conversion Factor	meq/kg	meq/100g
Na^+	2904.29	0.0435	126.34	12.63
Ca^{2+}	857.86	0.0499	42.81	4.28
Mg^{2+}	77.03	0.0823	6.33	0.63
K^+	63.23	0.0256	1.62	0.16

$$E\bar{S}P = [\bar{N}a^+]/([\bar{C}a^{2+} + \bar{M}g^{2+} + \bar{K}^+ + \bar{N}a^+]) \times 100 \quad (1)$$

$$S\bar{A}R = [\bar{N}a^+]/\sqrt{\frac{1}{2}([\bar{C}a^{2+} + \bar{M}g^{2+}])} \quad (2)$$

Table 2: $EC_{1:5}$ to EC_{se}

Section	$EC_{1:5}$ (dS/m)	Conversion Factor	EC_{se} (dS/m)
1	2.17	8.6	18.70
2	4.25	8.6	36.55
3	0.36	8.6	3.12
4	7.52	8.6	64.63
5	3.56	8.6	30.65

Discussion and Future Work

We discovered that the soil present at the private ranch site is unsuitable for even the salt tolerant plants that we grew. This is due to degraded soil structure (low permeability and porosity) as evidenced by our geochemical data. Furthermore, organic material is essential to improve soil structure as well as provide essential nutrients depleted within the soil necessary for plant growth.

Future work:

- Determine appropriate soil amendments based on geochemical data.
  - Gypsum: improve soil structure
  - Magnesium sulfate: increase Mg levels and improve structure
  - Compost: add organic material
- In a controlled setting (i.e., a greenhouse), determine viability of each amendment technique both in terms of plant growth and salt uptake.
- Once planted, ensure plant safety using sturdy cages surrounding bushes and a fence around the site perimeter.
- Understand discrepancies between physical soil characteristics and quantitative data from soil testing results.
- Continue soil testing as more plants are planted on the site to determine success of bioremediation techniques
- Apply effective techniques from this study to other brine water spill sites across West Texas.
- Develop a cost benefit analysis outline that can be modified for each site.

Conclusion

In conclusion, brine impacted soils have degraded structure (due to high SAR and ESP), and chemistries (due to high EC) that are unable to support viable plant life. Degraded soil structure impairs water infiltration, and a plant's ability for root penetration. The unfavorable chemistries increase pore pressure within roots, inhibiting the plants ability to uptake required nutrients and water.

References

A reference list is available upon request