SOIL TESTING: SATURATED PASTE INTERPRETATION

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ABSTRACT

Soils with neutral to alkaline pH of the Western United States often contain elevated levels of soluble salts and/or higher concentrations of sodium associated with native salts or irrigation water. Elevated concentrations of soluble salts limit crop growth and sodium may impact water management. Soil analysis based on the saturated paste extraction (SPE) method provides insight on soil texture, soluble salt content, cation/anion constituents, and information on soil hazards, such as salinity, and B toxicity which reduce plant growth and yield. Interpretation of lab analysis is essential to developing an effective management strategy. This presentation will provide an overview on soluble salts, electrical conductivity (EC_e), cation and anion constituents, sodicity, boron toxicity, and management interpretation. Laboratory example reports will be discussed for evaluating soluble salt constituent analyses and management.

INTRODUCTION

The soil saturated paste extraction (SPE) method is the preeminent method for the assessment of salinity in arid or semi-arid agricultural soils of the western U.S. Soils of this region are largely dependent on irrigation water supplied from surface water associated with rivers and lakes or pumped from underground aquifers. The irrigation water quality is specific to the geology of the source water and vary in both the total soluble salt content and the chemical constituents which impacts soil soluble salts. Calcium (C^{2+}), magnesium (Mg^{2+}), and sodium (Na^{1+}) comprise the dominant alkali cations in in the soil SPE, whereas chloride (Cl^{1-}), sulfate (SO_4^{2-}), nitrate (NO_3^{1-}), and bicarbonate (HCO_3^{1-}) comprise the dominant anions. The soil SPE may also contain dissolved carbonate (CO_3^{2-}) and boron (B) in lower concentrations dependent on pH and source geology. Additional trace elements may also be present but at concentrations of no relevance to agricultural production. This paper provides guidelines for the interpretation of soil SPE salinity and chemical constituents in the Western United States. These guidelines are based on the university extension guides and 215 soil samples collected across North America by the Agricultural Laboratory Proficiency (ALP) program.

DISCUSSION

With the application of irrigation water to soils, subsequent evapotranspiration leads to the accumulation of soluble salts in the soil root zone. High concentrations of salts of the alkali metals are detrimental to plant growth and productivity. The SPE method is frequently used by soil testing laboratories and agronomists to assess soil salinity, salt constituents, and their impact on soils. The method quantitatively determines the concentration of dissolved chemical ions in the soil solution that are not associated with soil minerals and organic matter. The SPE involves saturating soil with water whereby 100% of the total pore space is occupied by water, and no free water remains on the soil surface. Dissolved soil chemical ions are subsequently extracted and analyzed for elemental chemical constituents. The SPE is considered to be the best indicator of plant response to salinity compared with other ratio extractions (US Salinity Laboratory Staff

1954; Rhoades et al. 1989). The SPE provides relevant information on qualitative assessment of soil texture, soil pH, dissolved salts, salt chemical constituents, potential management information on salinity, sodicity, and/or B toxicity. Generally coarse textured soils (i.e. sands and sandy loams) have low saturation percentages, whereas fine textured soils (i.e. clay loams) containing greater clay content have greater total pore space and higher percentages (Table 1). At saturation, soil pH can be evaluated to assess relative alkalinity or acidity of a soil. Salinity is evaluated based on the electrical conductivity as well as the chemical composition of the soluble salts. From analysis of the salt constituents, the soil sodicity can be evaluated based on the SPE sodium absorption ratio (SAR) along with potential hazards such as supra-optimal B.

Table 1. Saturated paste moisture content and approximate soil texture range.

SPE (%)	Soil texture
< 20	Sand or loamy sand
20 – 35	Sandy loam
35 – 50	Loam or silt loam
50 – 65	Clay loam
65 – 135	Clay
> 80	Organic soils > 15% soil organic matter

US Salinity Laboratory Staff, 1954.

pH

pH of the SPE represents the relative acidity or alkalinity of soil. Soils with pH< 5.5 are strongly acid, whereas those with pH between 5.5-6.5 are mildly acid. Soils with pH between 6.5-7.5 are neutral, 7.5 – 8.5 are alkaline, and >8.5 are strongly alkaline. Soil pH impacts nutrient availability and may impact specific crop suitability.

Salinity

Soil salinity is evaluated based on electrical conductivity of the soluble salts dissolved in the SPE extract which is denoted as EC_e. Its units are expressed as either mmhos cm^{-1} or dSm^{-1}. EC_e increases proportionally to the amount of total dissolved salts. Soils low in salinity have $EC_e < 0.5$ dSm^{-1}, whereas soils with high amounts of total dissolved salts may have $EC_e > 3.0$ dSm^{-1}. Table 2 list general crop salinity ranges based on EC_e and specific crop sensitivities. Management of soils with high EC_e will require removal of salts though irrigation leaching and/or selection of tolerant crops. Soil soluble salt content is dynamic, and it changes with rainfall, irrigation water quality, and crop growth.

Calcium (Ca^{2+})

Calcium generally represents the dominant cation present in soil SPE extracts. Generally, soils low in EC_e (< 0.5 dSm^{-1}) have Ca concentrations < 3.5 meq L^{-1}, whereas soils with EC_e between 0.5 - 1.0 dSm^{-1} have Ca concentrations between 1.0 – 8.0 meq L^{-1}. Soils with EC_e > 2.0 generally contain Ca concentrations > 12 meq L^{-1}, with the exception of soils dominated by Mg or Na soluble salts. Soil SPE extracts with > 60% cations as Ca generally have higher water infiltration rates than those dominated by Mg or Na.

Table 2. Impact of saturated paste soil salinity (EC_e) on plant growth.

EC_e dS m^{-1}	Plant salinity effects, productivity reduced 25%.
0 - 2	Salinity effects negligible (field bean, carrot, onion, red clover strawberry)
2 - 4	Very sensitive crops affected (spinach, lettuce, citrus, grape, alfalfa)
4 - 8	Moderately salt tolerant crops affected (tomato, beet, wheat)
8 - 16	Only salt tolerant crops yield satisfactory (barley, wheatgrass cotton, asparagus)
> 16	Few salt tolerant crops yield satisfactory

Hanson, et al. 1993.

Magnesium (Mg^{2+})

Magnesium generally represents the 2nd most dominant cation present in soil SPE extracts. Generally, soils low in EC_e (< 0.5 dSm^{-1}) have Mg concentrations < 2.0 meq L^{-1}, whereas soils with EC_e between 0.5 - 1.0 dSm^{-1} have Mg concentrations between 0.3 - 4.6 meq L^{-1}. Soils with EC_e > 2.0 generally contain Mg concentrations > 3.0 meq L^{-1}, with the exception of soils dominated by Na soluble salts. Soils which have SPE Ca:Mg ratios < 2:1 may have lower water infiltration rates, and ratios < 1:1 with EC_e < 1.0 will essentially have no water infiltration below the soil surface.

Sodium (Na^{1+})

Generally, Na represents the 3rd most dominant cation present in soil SPE extracts. In general, soils low in EC_e (< 0.5 dSm^{-1}) have Na concentrations < 1.0 meq L^{-1}, whereas soils with EC_e between 1.0 – 2.0 dSm^{-1} have Na concentrations between 0.2 – 1.0 meq L^{-1}, with the exception of soils with < 55% of the total cations as Ca. Soils with > 40 % of the SPE total cations as Na are likely to defloculate and have a poor water infiltration.

Sodicity and SAR

Sodicity or sodium hazard of a soil is represented by the sodium absorption ratio (SAR). It represents the ratio between Na and the sum of Ca and Mg based on the valance of the individual cations in the soil SPE, as represented by the formula $SAR = [Na] / (([Ca]+[Mg])/2)^{1/2}$, with units expressed as millequivalents per liter (meq L^{-1}). Generally, soils with Na constituting < 20% of the total SPE cations have an SAR < 2.0, however, soils containing naturally occurring Na salts or irrigated with water containing elevated Na concentrations will likely have an SAR > 4.0. Soils with an SAR > 13 are classified as sodic. Although alkaline soils may be referred to as saline or sodic, a high soil pH does not infer either description.

The effects of salinity and sodium are defined by five classes: (1) non saline, $EC_e < 2.0$ dSm^{-1}; (2) saline slightly, $EC_e > 2.0 - 4.0$ dSm^{-1}; and SAR < 13; (3) saline, $EC_e > 4.0$ dSm^{-1} < and SAR < 13; (4) saline-sodic, $EC_e > 4.0$ dSm^{-1} and SAR > 13; and (5) sodic soil, $EC_e < 4.0$ dSm^{-1} and SAR > 13. When saline-sodic soils leached with low EC water, they become sodic. Management of saline soils require irrigation to leach soluble salts while sodic soils requires amendment with gypsum.

Potassium (K^{1+})

Soil SPE K is generally low for soils with < 1.0 meq L^{-1} and containing < 300 mg kg^{-1} exchangeable K. Soils containing higher concentrations of exchangeable K or receiving high application rates of K fertilizers may contain 1.0 - 3.0 meq L^{-1} K and have an $EC_e > 2.0$. Soils with K concentrations < 0.2 meq L^{-1} may have potential crop K deficiencies.

Chloride $(Cl)^{1-}$

Soil SPE Cl concentrations vary greatly dependent on: (1) proximity to an ocean source, (2) Cl content of the irrigation water source, (3) past use of manure amendments, and (4) the amount and Cl content of the applied fertilizers. Across soils Cl generally constitutes 1-40% of the total anions present in the SPE, but Cl concentrations > 5.0 meq L^{-1} are frequently noted on soils with pH > 7.4. Crop tolerance to Cl in the soil SPE is shown in Table 3 and is generally not an issue for sensitive crops on soils with SPE Cl < 10 meq L^{-1}.

Table 3. Tolerance of some plants to chloride (Cl) in the soil saturated paste extract.

Crop	Chloride (meq l^{-1})
Alfalfa	23
Barley	90
Beets	90
Citrus (root stock dependent)	10 - 25
Corn (2-8 leaf stage)	70
Cotton	50
Grapes (Thompson seedless)	25
Tomato	39
Wheat	25

Western Fertilizer Handbook, 1985.

Sulfate (SO_4^{2-})

Soil SPE SO_4 concentrations vary dependent on: (1) gypsum content of soil parent material, (2) SO_4 content of the irrigation water source (3) past use of manure amendments, (4) and/or previous applications of gypsum or sulfur containing fertilizers. Across soils, SO_4 generally constitutes 1-25% of the total anions present in the SPE. Alkaline soils > 25% of anions as SO_4 have EC_e > 2.0 dSm^{-1} and SPE Ca concentration > 10 meq L^{-1}. Generally, high soil SPE SO_4 concentrations impact soil salinity and crop growth.

Nitrate (NO_3^{1-})

Soil SPE NO_3 concentrations vary dependent on: (1) previous crop residue, (2) NO_3 content of the irrigation water source, (3) past use of manure amendments, and (4) the amount and type of applied fertilizers. Generally, soils with NO_3^- concentration < 3.0 meq L^{-1} have EC_e < 0.5 dSm^{-1}, with the exception of soils containing > 1.0 meq L^{-1} SO_4. Generally, for soils where NO_3 constitutes > 80% of the total soil SPE anions, Ca accounts for > 50% of the total cations. Soil SPE NO_3 concentration is highly dynamic, changing with rainfall/irrigation and crop NO_3 uptake.

Bicarbonate (HCO_3^{1-})

Soil SPE HCO_3 may constitute 1- 80% of the total anions present in the SPE, with highest concentrations on soils with pH > 5.8. For soils where NO_3 constitutes > 80% of the total SPE anions, HCO_3 generally accounts for < 5%. Generally, a majority of soils with HCO_3^- concentration > 3.0 meq L^{-1} have a pH value > 7.0. Soil HCO_3 concentrations may increase during crop growth associated with root respiration and NO_3 uptake. Soils with SPE HCO_3 concentrations > 10.0 meq L^{-1} have shown to impact vegetable crop root growth (Wallace and Rhoades, 1960). Soils with high SPE HCO_3 concentrations decrease Ca solubility, Ca uptake, and results in precipitation of ferric iron hydroxide ($Fe(OH)_3$) on soil minerals (Inskeep and Bloom, 1984).

Boron (B)

Soil SPE B, measured as mg L^{-1} in the extract solution, is generally < 0.5 mg L^{-1}. Elevated B concentrations are associated with: (1) soil parent materials high in B, (2) irrigation well water containing elevated B content (> 1.0 m L^{-1}), and/or (3) past use of applied B fertilizers. Generally, potential elevated SPE B is associated with soil EC_e > 2.0 dSm^{-1}. Crop tolerance to B in the soil SPE is shown in Table 4 and is generally not an issue for sensitive crops on soils with SPE B < 0.7 mg L^{-1}. Agronomic management of soils with high SPE B is a challenge, and generally limited to B tolerant crops.

SPE Interpretation

Saturated paste extract data of four soils diverse in chemical properties from the ALP Program are listed in Table 5. Two of the soils were classified as sandy loam (i.e., ID 0906 and

ID 1307) and the last two as loam (i.e. ID 1405 and ID 1508). Soil ID 0906 and ID1307 had similar soil pH but different soil SPE salinity. , Soil ID 1307 had substantially higher concentrations of Ca and Mg cations and SO_4 and NO_3 anions, and classified as saline. Soil ID 0906 had a SPE Ca:Mg ratio of 1.4 whereas ID 1405 had a ratio of 0.6, which is < 1:1, and likely to have a lower water infiltration with loss of soluble salts. Soil ID 1508 had a moderately high EC_e (saline), which would impact vegetable crops and an elevated SAR, which may require an amendment with gypsum. Of the four soils IDs 1508 had elevated Cl and B which would limit specific citrus tree root stocks and B sensitive crops. Soil ID 1307 had elevated SPE NO_3, which constitutes 86% of the total anion content. Subsequently plant NO_3 uptake would result in a potential lowering of the EC_e. For soil ID 1508, three anions, Cl, NO_3, and SO_4 constituted 95% of the total anions and irrigation with low EC water would reduce salinity, resulting in leaching of SPE Ca and Mg, and potentially result in a SAR > 13, and a sodic soil.

Table 4. Tolerance of some plants to boron in the soil SPE paste extract.

B mg L^{-1}	Plant sensitivity
< 0.7	Safe for sensitive plants (peach, pear, plum)
0.7 – 1.5	Moderate tolerance (cotton, wheat, bell pepper)
1.5 – 4.0	Toxic to all but tolerant plants (alfalfa, lettuce, sugar beet)
> 4.0	Generally toxic to all plants

Hanson et al. 1993.

Table 5. Comparison of soil SPE constituents of four ALP soils, median values reported.

SPE Parameter	Soil ID 0906	Soil ID 1307	Soil ID 1405	Soil ID 1508
Sat Paste Moist. (%)	28.6	23.0	33.1	36.6
pH	5.7	5.9	6.8	7.7
EC_e (ds/m^{-1})	0.34	4.3	1.8	4.6
Ca (meq/L^{-1})	0.70	25.6	5.2	16.0
Mg (meq/L^{-1})	0.51	17.8	8.6	3.5
Na (meq/L^{-1})	0.15	0.61	4.1	27.9
SAR	0.62	0.14	1.5	9.0
HCO_3 (meq/L^{-1})	0.33	0.86	2.6	1.4
Cl (meq/L^{-1})	0.73	0.90	2.6	17.3
SO_4 (meq/L^{-1})	0.76	6.1	1.8	18.0
NO_3 (meq/Lm^{-1})	1.2	37.3	9.7	10.7
B mg L^{-1}	0.05	0.11	0.05	0.93

Overall, the SPE method provides qualitative information on soil texture, quantitative information on soil acidity/alkalinity, soil salinity, cation and anion constituents, and sodicity. It provides the basis for making sound agronomic management decisions for irrigated arid and semi-arid soils of the Western US.

LITERATURE

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