soil Electrical Conductivity

Soil Quality Kit – Guides for Educators

United States Department of Agriculture
Natural Resources Conservation Service

Soil electrical conductivity (EC) is a measure of the amount of salts in soil (salinity of soil). It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and activity of soil microorganisms which influence key soil processes including the emission of greenhouse gases such as nitrogen oxides, methane, and carbon dioxide. Excess salts hinder plant growth by affecting the soil-water balance. Soils containing excess salts occur naturally in arid and semiarid climates. Salt levels can increase as a result of cropping, irrigation, and land management. Although EC does not provide a direct measurement of specific ions or salt compounds, it has been correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia. For certain non-saline soils, determining EC can be a convenient and economical way to estimate the amount of nitrogen (N) available for plant growth.

Inherent Factors Affecting Soil EC

Inherent factors affecting EC include soil minerals, climate, and soil texture which cannot be changed. Salts originate from disintegration (weathering) of minerals and rocks. In areas with high amounts of rainfall, soluble salts from minerals and rocks are flushed below the root zone, eventually into deep groundwater systems or into streams that transport salts to the ocean. Conversely, in arid areas or in areas where less rainfall occurs or saline irrigation water is used, soluble salts are more likely to accumulate and remain near the soil surface, resulting in high EC. Salt-affected soils mainly occur in the western United States; in arid or semiarid areas where annual rainfall is low.

Because salts move with water; low areas, depressions or other wet areas where water accumulates tend to be higher in EC than surrounding higher-lying, better drained areas. Clay soils dominated by clay minerals that have a high cation-exchange capacity (CEC), such as smectite, have higher EC than clay soils dominated by clay minerals that have a low CEC, such as kaolinite. Soils with restrictive layers, such as claypans, typically have higher EC because salts cannot be leached from the root zone and accumulate on the surface. Infiltration water can also interact with underlying bedrock that weathers releasing salts which creates saline seeps where it exits.

Salinity Management

Soil EC is affected by cropping, irrigation, land use, and application of fertilizer, manure, and compost. When managing for salinity on irrigated land, irrigation water salinity must also be measured. Irrigating in amounts too low to leach salts, or with water high in salts, allows salts to accumulate in the root zone, increasing EC.

Existing salinity levels and amount of salt contained in manure and municipal waste need to be closely monitored to prevent salinity problems, especially in arid climates. Nitrogen fertilizer application can increase salinity and should be monitored closely, especially on sites with potential salinity concerns.

Management that leads to low organic matter, poor infiltration, poor drainage, saturated soil, or compaction can increase EC and the soil's ability to buffer EC.

When irrigating, additional water beyond crop needs can be used to flush excessive salts below the root zone and maintain a EC level, which is based on crop tolerance. Care is needed when applying extra water to leach salts because soils can become waterlogged, allowing salts to accumulate. Leaving crop residue on the surface limits evaporation, and retains soil moisture allowing rainfall and irrigation to be more effective in leaching salts. In some cases, a combination of irrigation, and drainage is necessary to reduce salinity. Good soil management measures to maintain soil organic matter and overall soil health, must be utilized to maintain the desired EC level.

Problems Related to EC and Relationship of EC to Soil Function

Electrical conductivity levels can serve as an indirect indicator of the amount of water and water-soluble nutrients available for plant uptake such as nitrate-N. Areas of saline soils need to be identified and managed differently from areas of non-saline soils. Soil microorganism activity declines as EC increases. This impacts important soil processes such as respiration, residue decomposition, nitrification, and denitrification (Table 1).

Soils with a high concentration of sodium salts (sodic conditions) have additional problems, such as poor soil structure, poor infiltration or drainage, and toxicity for many crops. Each crop has a salt tolerance. Table 3 shows the percent yield reduction based on the soil EC levels.

$EC_{1:1}$ readings less than 1 dS/m, soil are considered non-saline (Table 2) and do not impact most crops and soil microbial processes (Tables 1 and 3). $EC_{1:1}$ readings greater than 1 dS/m, are considered saline and impact important microbial processes, such as nitrogen cycling, production of nitrous and other N oxide gases, respiration, and decomposition; populations of plant-parasitic nematodes can increase; and increased nitrogen losses.

Even slight to moderate salinity can impede crop growth as shown in Figure 1.

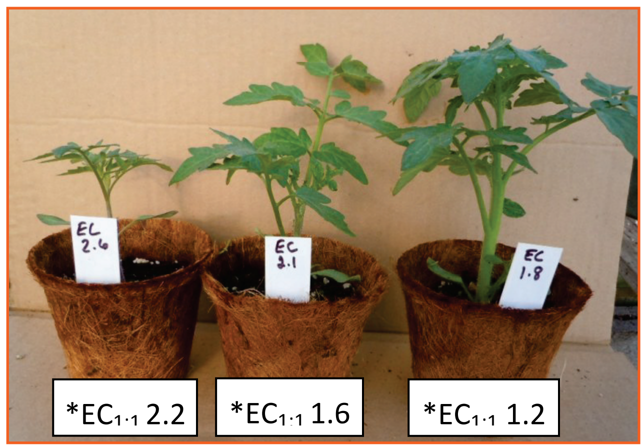

Figure 1. EC1:1 values using compost and tap water for tomatoes (Gage, 2012).

* EC1:1 values of compost adjusted for well water EC values of 1.0 dS/m to values for distilled water are shown as footnoted values below each pot in Figure 1. Compost $EC_{1:1}$ readings were adjusted as follows: distilled water = Compost $EC_{1:1}$ in well water – (EC of well water / Compost $EC_{1:1}$ with well water) = 2.6 – (1/2.6) = 2.6- (.385) = 2.22 dS/m.

Table 1. Soil EC influence on microbial processes and gaseous N production in soils amended with sodium chloride (NaCl) or nitrogen fertilizers (after Smith and Doran, 1996 (Tables 10-5 & 10-6) and Adviento-Borbe et al., 2006).

Process	$EC_{1:1}$ Range (dS/m)	Relative Decrease/Increase (%)	Threshold $EC_{1:1}$
Respiration	0.7 to 2.8	-17 to -47	0.7
Decomposition	0.7 to 2.9	-2 to -25	0.7
Nitrification	0.7 to 2.9	-10 to -37	0.7
Denitrification	1.0 to 1.8	+32 to +88	1.0
*Anaerobic N_2O gas production (high nitrate)	0.02 to 2.8	+1500 to +31,500	1.0-1.5
*Anaerobic N_2O gas production (low nitrate)	0.5 to 2.0	+ 200 to + 90,000	0.7-1.0

*EC values above 1.0 dS/m increase production of nitrous oxide **(N_2O)** gas from denitrification under anaerobic conditions (90% or more water-filled pore space) by over 15 to 315 fold with relatively high nitrate levels. Nitrous oxide is nearly 300 times more potent than carbon dioxide (CO2) as a greenhouse gas and depletes ozone in the upper atmosphere.

Table 2. Salinity classes and relationship between $EC_{1:1}$ to ECe values (Smith and Doran, 1996 adapted from Dahnke & Whitney, 1988).

Texture	Degree of Salinity (Salinity Classes)					
	Non-Saline	Slightly Saline	Moderately Saline	Strongly Saline	Very Saline	Ratio of $EC_{1:1}$ to ECe
$EC_{1:1}$ Method (dS/m)						
Coarse to loamy sand	0-1.1	1.2-2.4	2.5-4.4	4.5-8.9	9.0+	0.56
Loamy fine sand to loam	0-1.2	1.3-2.4	2.5-4.7	4.8-9.4	9.5+	0.59
Silt loam to clay loam	0-1.3	1.4-2.5	2.6-5.0	5.1-10.0	10.1+	0.63
Silty clay loam to clay	0-1.4	1.5-2.8	2.9-5.7	5.8-11.4	11.5+	0.71
ECe Method (dS/m)						
All textures	0-2.0	2.1-4.0	4.1-8.0	8.1-16.0	16.1+	NA

Table 3. Salt tolerance and yield decrease beyond EC threshold (Smith and Doran, 1996; $EC_{1:1}$ based on Hoffman & Maas 1977).

Crop(s)	Threshold EC_e (dS/m)	Threshold $EC_{1:1}$ (dS/m)	Yield Decrease (%) per $EC_{1:1}$ Unit (dS/m) Beyond Threshold
Barley	8.0	4.5 to 5.7	5.0
Cotton	7.7	4.3 to 5.5	5.2
Sugar beet	7.0	3.9 to 5.0	5.9
Wheat	6.0	3.4 to 4.3	7.1

Ryegrass, perennial	5.6	3.1 to 4.0	7.6
Soybean	5.0	2.8 to 3.6	20.0
Tall Fescue	3.9	2.2 to 2.8	5.3
Wheatgrass, crested	3.5	2.0 to 2.5	4.0
Peanut	3.2	1.8 to 2.3	29.0
Rice; Vetch, common	3.0	1.7 to 2.1	12.0
Tomato	2.5	1.4 to 1.8	9.9
Alfalfa	2.0	1.1 to 1.4	7.3
Corn & Potato	1.7	1.0 to 1.2	12.0
Clover, berseem; Orchardgrass; Grapes; Peppers	1.5	0.8 to 1.1	5.7
Lettuce & Cowpea	1.3	0.7 to 0.9	13.0
Green Bean	1.0	0.6 to 0.7	19.0

What current practices do you think affect soil EC?

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What impact do you expect these practices to have on soil EC and why?

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Measuring Soil EC (Using $EC_{1:1}$ Method)

Materials Needed to Measure Soil EC

____ Soil probe and plastic bucket for gathering and mixing soil samples

____ 1/8-cup (29.5-mL) measuring scoop

____ Squirt bottle

____ Distilled water or rainwater

____ Calibrated 120-mL shaking vial with lid

____ EC probe (blue with black cap)

____ Probe holder with field calibration resistor (470 ohm)

____ 1.41-dS/m calibration solution

____ Pen, field notebook, sharpie, and zip-lock bags

Considerations – Because soil EC is variable, multiple samples should be taken from multiple locations. Look over sampling area for large bare spots, areas with short plants, areas where plants are growing better, or other areas of possible salinity. These areas should be sampled separately.

Step-by-Step Procedure

Calibration: Ensure EC probe is calibrated before starting. Calibrate EC probe by immersing it in a standard salt solution (1.41 dS/m) at 25 degrees C (77 degrees F) and turning adjustment knob on probe with a screwdriver until probe reads 1.4, then insert EC probe (Figure 2) into calibration resistor on probe holder and record reading for future use. Future readings are taken at the same temperature.

Figure 2. EC probe inserted into resistor on holster to check calibration (Doran & Kucera, 2012).

1. Soil Sampling: Soil EC level is highly variable, depending on past management, field location and time of the year. Examples include, fertilizer placement in rows vs. between rows, soil texture, organic matter content, and applications of manure or fertilizer. Using a soil probe gather at least 10 small samples randomly from an area that represents soil type and management history to a depth of 8 inches and place in a small plastic bucket. Do not include large stones and residue in the sample. Repeat this step for each sampling area.
2. Tamp down one sampling scoop (29.5 mL) of mixed soil by striking scoop carefully on a hard level surface and place soil in plastic mixing vial. Add one scoop (29.5 mL) of distilled water to the same vial. The vial will contain a 1:1 ratio of soil to water, on a volume basis.
3. Tightly cap vial and shake 25 times.
4. Remove cap, turn on EC probe, and insert into soil-water mixture in vial, keeping the probe tip well in the center area of the soil suspension. Take reading while soil particles are still suspended in solution. To keep soil particles from settling, stir gently with EC probe. Do not immerse probe above maximum immersion level.
5. After reading stabilizes for about 10 seconds, record $EC_{1:1}$ in dS/m.
6. Save soil-water mixture for measurement of pH, nitrate, nitrite, and phosphorus, if applicable.
7. TURN OFF and thoroughly rinse EC probe with distilled water and replace cap.

Interpretations

Record soil $EC_{1:1}$ reading(s) and complete the rest of Table 4 by comparing readings to values in Tables 1, 2, and 3 and answering discussion questions.

Table 4. Soil EC (salinity) in surface soil and interpretations.

Site	Soil $EC_{1:1}$ (dS/m)	Texture	Degree of Salinity	pH	*Nitrate Estimate (ppm)	Microbial Processes Impacted	Crops Impacted	Notes:
No Till	0.3	Silt loam	Non-saline	7.0	42	N/A	N/A	42 ppm is adequate for corn N needs
Conven-tional Till	1.2	Silt loam	Slightly saline	7.8	NA	Respiration, decomposition, and nitrification decrease; nitrogen loss (N_2 & N_2O) through denitrification increases	Alfalfa and vegetables	Reading taken after N fertilizer applied

***** Soil nitrate levels can be approximated in non-saline soils with a pH less than 7.2, using this equation:

140 x $EC_{1:1}$ (in dS/m) < or = soil nitrate-nitrogen in ppm.

For example; 140 X 0.01 dS/m = 1.4 ppm nitrate-nitrogen.

Were results of soil EC test what you expected? Why or why not?

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Compare soil EC results to values in Tables 1, 2, and 3. Are EC levels ideal for crops or forages grown and soil microbial processes? Why or why not?

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Glossary

Cation-Exchange Capacity (CEC) – Capacity of soil to exchange cations (positively charged ions). High clay or organic matter content soils have a higher CEC than low organic matter or sandy soils.

Denitrification – Conversion and loss of nitrate nitrogen to atmosphere in various gas forms, due to lack of oxygen when soil becomes saturated with water.

dS/m – Unit of measurement for electrical conductivity of soil in deciSiemens per meter.

EC_e Method – Standard accepted laboratory method for soil EC testing using a saturated paste extract (does not need to be adjusted for soil texture). Table 2 provides a relationship between $EC_{1:1}$ and EC_e values.

$EC_{1:1}$ Method – Soil EC testing method described in this document using a 1:1 soil-water mixture that must be adjusted for soil texture (refer to Table 2).

Nitrification – Conversion of ammonium compounds in organic material, or fertilizer into nitrites and nitrates by soil bacteria, making nitrogen available to plants.

Nitrogen Oxides – Family of nitrogen gases that can be generated by human activities and released to atmosphere. Losses of nitrogen gases from soils increase 10 to 100 fold through nitrification, under dry soil conditions; or through denitrification, under saturated soil conditions. Soil losses of nitrogen oxide gases also increase, when EC values are above 1 to 2 dS/m.

Respiration – Release of carbon dioxide (CO_2) from soil due to soil biological activity (i.e., microorganisms and roots) and decomposition.

Saline/Sodic Soil – Saline soils have a high content of soluble salts that negatively affect soil processes, productivity and overall soil health. As sodium (Na^+) predominates, saline soils can become *sodic*. Sodic soils present particular challenges because they tend to have poor structure, preventing water infiltration and drainage.

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