Soil electrical conductivity (EC) is a measure of the amount of salts in soil (salinity of soil). It is an excellent indicator of nutrient availability and loss, soil texture, and available water capacity. It affects crop yields, the suitability of the soil for certain crops, the amount of water and nutrients available for plant use, and the activity of soil micro-organisms, which influences key soil processes such as the emission of greenhouse gases, including nitrogen oxides, methane, and carbon dioxide. Excessive salts hinder plant growth by affecting the soil and water balance. Soils containing excessive 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 nonsaline soils, determining EC can be an easy, economical way to estimate the amount of nitrogen (N) available for plant use. Soil EC can also be an effective way to determine the texture of the surface layer because smaller clay particles conduct more electrical current than larger silt and sand particles.

Inherent Factors Affecting Soil EC

Inherent factors affecting EC include soil minerals, climate, and soil texture. Other factors include bulk density, soil structure, water potential, timing of measurement, soil aggregation, and electrolytes in soil water. Salts originate from the disintegration (weathering) of minerals and rocks. In areas that receive a high amount of rainfall, soluble salts are flushed below the root zone and eventually into deep groundwater systems or into streams that transport the salts to the ocean. Nonsaline soils that have a higher EC value have more available nutrients than those that have a lower EC value.

In arid areas, areas that receive less rainfall, and areas where saline irrigation water is applied, soluble salts are more likely to accumulate and remain near the soil surface, resulting in high EC. Salt-affected soils are mainly in the western part of the United States, in arid or semiarid areas where the annual rainfall is low.

Low areas, depressions, or other areas where water accumulates tend to have higher EC than surrounding higher lying, better drained areas. Water that infiltrates into soils can interact with the underlying bedrock and other material that weathers, releasing salts and creating saline seeps on side slopes. This occurs at the loess-till interface in areas where loess soils are underlain by glacial till.

Soils that have a higher content of smaller soil particles (higher content of clay) conduct more electrical current than do soils that have a higher content of larger silt and sand particles (lower content of clay). Soils that consist dominantly of clay minerals that have a high cation-exchange capacity (CEC), such as smectite, can have higher EC than soils that consist dominantly of clay minerals that have a low CEC, such as kaolinite. Soils that have a restrictive layer, such as a claypan, typically

have higher EC. The salts accumulate on the soil surface because the restrictive layer limits water flow; thus, they cannot be leached from the root zone.

Salinity Management

Soil EC is affected by cropping, irrigating, land use, and application of fertilizer, manure, and compost. When managing for salinity on irrigated land, the salt content of the irrigation water must be determined. Applying irrigation water in amounts too low to leach salts or applying water that is high in content of salts results in an accumulation of salts in the root zone, increasing EC.

Existing salinity levels and the amount of salts in manure and municipal waste need to be closely monitored, especially in arid climates. Nitrogen fertilizer can also increase salinity, especially in areas where it is already a potential concern.

Management that leads to low organic matter content, poor infiltration, poor drainage, saturated soil conditions, or compaction can increase salinity and decrease the ability of the soil to support some plants.

When irrigating, applying more water than is needed for crops can help to leach excess salts below the root zone and maintain the desired EC level for the crop grown. Care is needed when applying excess irrigation water because the soil can become waterlogged, allowing salts to accumulate. Leaving crop residue on the surface limits evaporation and helps to retain soil moisture, allowing rainfall and irrigation water to be more effective in leaching salts. In some areas, both irrigation and drainage are needed to reduce salinity. Proper soil management to maintain the organic matter content and overall soil health is needed to keep EC at the desired level.

Problems Related to EC and Relationship of EC to Soil Function

Areas of saline soils need to be managed differently than areas of nonsaline soils (e.g., different crops and irrigation practices). Soil micro-organism activity declines as EC increases above the desired level. This impacts important soil processes such as respiration, residue decomposition, nitrification, and denitrification (table 1).

A high concentration of sodium salts (sodic conditions) in soils can result in poor soil structure, poor infiltration or drainage, and toxicity for many crops. Each crop has a particular salt tolerance. Table 3 shows the percent reduction in yields based on the soil EC level.

Soils that have $EC_{1:1}$ of less than 1 deciSiemen per meter (dS/m) are considered to be nonsaline (table 2). Salinity in these soils does not affect most crops and soil microbial processes (tables 1 and 3). Soils that have $EC_{1:1}$ of more than 1 dS/m are considered to be saline. Important microbial processes, such as nitrogen cycling, production of nitrous gases and other N oxide gases, respiration, and decomposition of organic matter are affected. Populations of parasitic nematodes and loss of nitrogen can be higher in these soils.

Even slight to moderate salinity can impede crop growth, as shown in figure 1. In nonsaline soils, EC levels can be an indirect indicator of the amount of water-soluble nutrients, such as nitrate nitrogen, available for plant use.
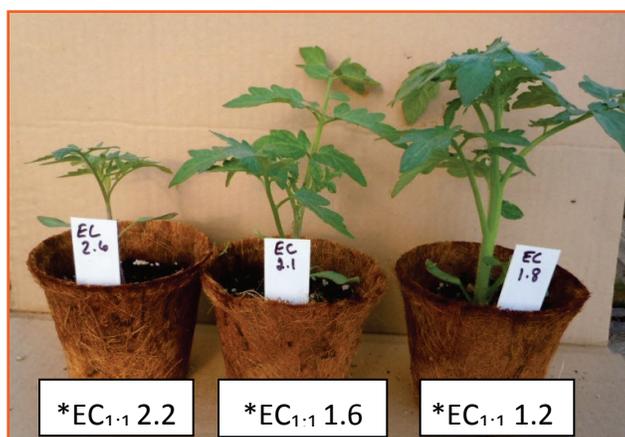
| *EC$_{1:1}$ 2.2 | *EC$_{1:1}$ 1.6 | *EC$_{1:1}$ 1.2 |

Figure 1.—EC$_{1:1}$ values for tomatoes, using three types of compost with different EC values and tap water (Gage, 2012).

  *EC$_{1:1}$ value using compost and distilled water that has no EC value (0 dS/m). The EC$_{1:1}$ value was adjusted using the formula: EC$_{1:1}$ value of compost with tap water – (EC of tap water ÷ EC$_{1:1}$ of compost with tap water). For example, the EC value of the smallest tomato plant with tap water is 2.6; therefore, 2.6 - (1 ÷2.6) = 2.6 - (0.385), or 2.22 dS/m with distilled water.

Table 1.—Soil EC influence on microbial processes and gaseous N production in soils amended with sodium chloride (NaCl) or nitrogen fertilizer (adapted from Smith and Doran, 1996 (tables 10-5 & 10-6) and Adviento-Borbe and others, 2006).

Process	EC$_{1:1}$ range (dS/m)	Relative decrease/increase (percent)	EC$_{1:1}$ threshold
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$_2$O gas production (high nitrate)*	0.02 to 2.8	+1500 to +31,500	1.0-1.5
*Anaerobic N$_2$O gas production (low nitrate)	0.5 to 2.0	+ 200 to + 90,000	0.7-1.0

  *Soils that have an EC value of more than 1 dS/m and a relatively high nitrate level will have increased production of nitrous oxide (N$_2$O) gas by denitrification under anaerobic conditions (90 percent or more water-filled pore space) by more than 15 to 315 times. Nitrous oxide is nearly 300 times more potent than carbon dioxide (CO$_2$) as a greenhouse gas that depletes ozone in the upper atmosphere.

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

Texture	Degree of salinity (salinity classes)					Ratio of $EC_{1:1}$ to EC_e
	Nonsaline	Slightly saline	Moderately saline	Strongly saline	Very strongly saline	
$EC_{1:1}$ method (dS/m)						
Coarse sand 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
EC_e method (dS/m)						
All textures	0-2.0	2.1-4.0	4.1-8.0	8.1-16.0	16.1+	N/A

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

Crops	EC_e threshold (dS/m)	$EC_{1:1}$ threshold (dS/m)	Percent decrease in yields 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 beets	7.0	3.9 to 5.0	5.9
Wheat	6.0	3.4 to 4.3	7.1
Perennial ryegrass	5.6	3.1 to 4.0	7.6
Soybeans	5.0	2.8 to 3.6	20.0
Tall fescue	3.9	2.2 to 2.8	5.3
Crested wheatgrass	3.5	2.0 to 2.5	4.0
Peanuts	3.2	1.8 to 2.3	29.0
Rice, common vetch	3.0	1.7 to 2.1	12.0
Tomatoes	2.5	1.4 to 1.8	9.9
Alfalfa	2.0	1.1 to 1.4	7.3
Corn, potatoes	1.7	1.0 to 1.2	12.0
Berseem clover, orchardgrass, grapes, peppers	1.5	0.8 to 1.1	5.7
Lettuce, cowpeas	1.3	0.7 to 0.9	13.0
Green beans	1.0	0.6 to 0.7	19.0

What current practices affect soil EC?

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What impact do these practices have on soil EC? Why?

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Measuring Soil EC (EC$_{1:1}$ Method)

Materials needed to measure soil EC:

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

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

____   Squirt bottle

____   Distilled water or rainwater

____   Calibrated 120-mL 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, permanent marker, and resealable plastic bags

Considerations:

Because soil EC is variable, multiple samples should be taken from multiple locations. Soil EC levels vary depending on past management, field location, and time of year. Examples of variables include placement of fertilizer in rows versus between rows, soil texture, organic matter content, and applications of manure or fertilizer. Scan sampling area for large bare spots, areas with short plants, areas with better plant growth, and areas with possible indications of salinity (salts may be visible at the soil surface). Each of these areas should be sampled separately.

*Step-by-step procedure:

1. Calibrate EC probe by immersing in a standard salt solution (1.41 dS/m) at 25 °C (77 °F) and turning the adjustment knob on the probe to 1.4 with a screwdriver. Second, insert EC probe (fig. 2) into calibration resistor on probe holder. Record reading. Future readings are taken at the same air temperature.

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

2. Using a soil probe, gather at least 10 randomly selected samples from an area that represents a particular soil type, condition, and management history. The probe should extent to a depth of 8 inches or less. Place samples in the small plastic container and mix. Do not include large stones and plant residue. Repeat step 1 for each sampling area.

3. Fill one scoop (29.5 mL) with mixed soil, tamping down during filling by carefully striking scoop on a hard, level surface. Place soil in calibrated vial. Add one scoopful (29.5 mL) of distilled water. The vial will contain a 1:1 ratio of soil to water, on a volume basis.

4. Tightly cap vial and shake 25 times.

5. Remove EC probe cap, turn probe on, and insert probe into soil and water mixture in vial, keeping the tip of the probe in the center of the suspended soil particles. 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 below maximum immersion level.

6. Reading will stabilize in about 10 seconds. Record EC$_{1:1}$ as dS/m.

7. Save soil and water mixture to measure pH, nitrates, nitrites, and phosphorus, if applicable. Nitrate levels can be estimated for soils that are nonsaline and have a pH of less than 7.2 if nitrates make up most of the soluble salts in the EC reading. Use the equation—140 x $EC_{1:1}$ </= soil nitrate nitrogen, expressed as ppm. For example, 140 x 0.03 dS/m </= 4.2 ppm nitrate nitrogen.

8. **Turn off** probe, thoroughly rinse with water, and replace cap.

*Note that the EC test can be conducted in the field by inserting the EC probe into the soil to the desired depth and saturating the soil with distilled water. This simulates the EC1:1 test.

Interpretations

Record soil $EC_{1:1}$ readings. Complete table 4 by comparing EC readings to values in tables 1, 2, and 3 to determine the relative level of salinity and the microbial processes and crops that might be impacted by the salinity. Answer discussion questions.

Table 4.—Soil EC level (salinity) of upper part of 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	Nonsaline	7.0	42	N/A	N/A	Nitrate level of 42 ppm is adequate for corn.
Conventional till	1.2	Silt loam	Slightly saline	7.8	N/A	Decrease in respiration, decomposition, and nitrification; increase in loss of nitrogen (N_2 and N_2O) through denitrification	Alfalfa and vegetables	Reading taken after nitrogen fertilizer was applied.

Were results of soil EC test 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 forage plants and for soil microbial processes? Why or why not?

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Glossary and References

Glossary

Cation-exchange capacity (CEC).—Capacity of soil to hold cations (positively charged ions) on surface of negatively charged clay and soil organic matter and release them to the soil solution to be used by plants, to be leached, and/or to be used for biological processes. Soils that have a high content of clay or organic matter have a higher CEC than those that have a low content of organic matter or are sandy.

DeciSiemens per meter (dS/m).—Unit of measurement for soil electrical conductivity. Equivalent to millimhos per centimeter.

Denitrification.—Conversion and loss of nitrate nitrogen to the atmosphere as various forms of gas due to a lack of oxygen in soil when it is saturated with water.

EC$_e$ method.—Saturated past method for measuring soil EC, which is the standard laboratory method (adjustment for soil texture not needed). See table 2 for the relationship between EC$_{1:1}$ and EC$_e$ values.

EC$_{1:1}$ method.—Method for measuring soil EC using a 1:1 ratio of soil and water (adjustment

for soil texture needed). See table 2 for the relationship between EC$_{1:1}$ and EC$_e$ values.

Loess.—Soil consisting of eolian sediment, which is an accumulation of windblown silt. Loess typically is homogeneous and highly porous.

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

Nitrogen oxides.—Nitrogen gases that can be generated by human activity and released into the atmosphere. Loss of nitrogen gases from soils increases 10 to 100 times by nitrification when the soils are dry and by denitrification when the soils are saturated. Loss of nitrogen oxide gases also increases when soil EC is more than 1 to 2 dS/m.

Respiration.—Release of carbon dioxide (CO_2) from soil as a result of biological activity (i.e., micro-organisms and roots) and decomposition of organic matter.

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^+) becomes dominant, saline soils can become sodic. Sodic soils tend to have poor structure, which restricts water infiltration, soil aeration, and drainage.

Till.—Soils that formed in till or glacial till are made up of extremely heterogeneous sediment of glacial origin. These soils consist of clay to mixed clay, sand, gravel, and boulders. Till typically is less porous than loess, and water seeps can form on hillsides in areas where loess overlies till.

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