Salinity Management – Soil and Cropping Systems Strategies

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Introduction

Salt problems occur on approximately one-third of all irrigated land in the world. Some soils are salty because parent materials weather to form salts; while on croplands, salts may be carried in irrigation water, added as fertilizers or other soil amendments, or be present due to a shallow saline groundwater. The salt load of a soil is typically estimated by measuring electrical conductivity (EC). Positively-charged cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) join with negatively-charged anions (Cl^{-}, SO_4^{-}, HCO_3^{-}) to form soluble salts (NaCl, $CaCl_2$, $MgCl_2$, $CaSO_4$, $CaCO_3$, and KCl). In a solution, the ions disassociate and will move toward an electrode of the opposite charge, creating a current that can be measured with an EC meter. When the solution comes from a soil saturated paste, the abbreviation used is ECe, and when the solution is water, the abbreviation is ECw. A saline soil is one having an ECe greater than 4 dS/m. In addition to EC, a salt-affected soil may be characterized by sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP). Both SAR and ESP characterize the sodium status of an alkaline soil (a soil with pH greater than 8.5). A sodic soil is one having a SAR of at least 13.

Effects of Salinity on Plant Growth

Salt directly impairs plant growth by exerting osmotic stress that results in decreased turgor pressure in plant cells, by causing specific ion toxicities that vary by plant species, or by degrading soil conditions that limit plant water availability. Osmotic stress is the most common means by which salt impairs plant growth (Hanson et al., 2006). Under a low salinity condition, the concentration of solutes is higher in plant roots than in the soil-water solution. This means that water moves freely into the plant roots because there is more force, called osmotic potential, pulling the water into the plant roots than there is force holding the water to the soil particles. Under conditions of higher soil salinity, plants must transport solutes within the plant to the roots in order to keep root solutes higher than soil-water solution solutes to avoid water stress. Remobilizing solutes requires energy, and that energy, then, is not used for plant growth. Thus, some plants will not show specific salt-induced symptoms as a result of saline soil conditions; rather, they may just exhibit lower growth or generic stunting which may or may not be realized by the farmer as being salt-induced (Hanson et al., 2006).

Plant growth may also be impaired by specific ions, like sodium (Na^{+}), chloride (Cl^{-}), or boron (B), which can accumulate in plant stems and leaves. When toxic concentrations of Cl^{-} or B occur in plant leaves, it appears as yellowing and progresses to burning along the leaf edges. The presence of Na^{+}, in addition to specific toxicity, may limit plant calcium, magnesium, or potassium uptake, and therefore, result in plant nutrient deficiencies. When leaves yellow or burn, it reduces their photosynthetic capacity, thus reducing plant growth.

In addition to the direct effects of salinity on plants, plants may also be affected by salinity if soil conditions are degraded and water infiltration and drainage are impaired. Degraded soil conditions may exhibit white or black crusts or wet spots on the soil surface. The white crusting is the result of evapoconcentration of salts on the soil surface, and the black crusts form because humus is carried upward with water as water evaporates. Slick spots form because the soil particles are completely dispersed and soil structure is lost. The soil swells, and water infiltration will decrease. Poor infiltration can result in standing water on the soil surface or poor aeration in the soil pores, neither of which promotes plant health and growth.

Strategies for Salinity Management

In considering strategies for managing salinity, one should recognize the difference between applied water salinity and soil salinity. Crop salinity tolerances are expressed as both seasonal average applied water salinity and average root zone soil salinity. Irrigation water carries salts, and when irrigation water is applied to fields, salts are added to the soil. Salts accumulate in the soil at higher concentrations than they existed in the applied water. Also, salts may accumulate unevenly in the soil. For all of these reasons, it is important to test water and soil salinity regularly to understand baseline conditions and changes over time. With this knowledge, strategies like site selection, variety selection, soil amendments, and leaching may be employed to assist in salinity management.

Site Selection

Site selection is arguably the most important time to consider salinity management. Before a crop is planted, the irrigation water and soil should be tested for salinity. Preferably, the irrigation water should be tested over a span of time that would represent the irrigation season because crop tolerance values are expressed as the seasonal average applied water salinity. Soil may be tested for nutrient status on an annual basis, and EC may be a part of the nutrient status testing package. Consider, however, how deep the soil has been sampled for those tests. If soil salinity is a concern, soil should be tested in 6- to 12-inch increment depths to at least two feet. Increment depth samples should be kept separate for analysis. Several soil cores should be sampled over similar soil type. Over time, growers may not be aware of the salinity of their soil profile if soil has not been sampled and tested to sufficient depth. Management practices, like deep ripping before planting a permanent crop, or conditions of fluctuating shallow ground water, may redistribute salts that accumulated below the root zone of annual crops to a shallower level in the soil profile that could impact a subsequent crop. Limited water supplies due to drought and precision irrigation methods can exacerbate soil salinity. Growers should consider whether there are seasonal patterns of salinity or patterns across the field. These may indicate a need for managed off-season leaching or modifications to irrigation. In gravity-fed systems, modifications to irrigation may include increasing the on-flow rate of irrigation water, narrowing border checks, or shortening row length. If more than one irrigation source is available, consider using the best source, or mixing poorer quality water with better quality water, on seedling crops. Alfalfa seedlings, for example, have shown delayed emergence under saline conditions (Cornacchione and Suarez, 2015). Therefore, it is important to strive for low salinity soil conditions at the time of planting and use the best quality water available on seedlings.

Variety Selection

Relative salt tolerance ratings (i.e. sensitive, moderately sensitive, moderately tolerant, and tolerant) have been developed for various crops grown in California (Hanson et al., 2006). Tolerance thresholds at which yields are expected to decline have been developed for various crops (Ayers and Westcot, 1985) and serve as guidelines for crop selection, but absolute tolerance will vary depending on climate, soil conditions, cultural practices (Ayers and Westcot, 1985), crop stage of development (Smith, 1994), and variety characteristics (Cornacchione and Suarez, 2015). Some alfalfa varieties may tolerate higher salinity based on the plant's ability to exclude Na^+ concentrations in the shoots and limit Cl^- uptake (Cornacchione and Suarez, 2015). Nevertheless, recognizing that growers need to select crop varieties for various characteristics, including yield potential, disease and insect resistance, and other objectives in mind, plant breeding should not be considered a substitute for soil salinity management.

Soil Amendments

Soil amendments are most effective in alleviating salinity conditions in saline-sodic and sodic soils because in these soils Na^+ is the dominant cation. Calcium amendments can replace Na^+ on the soil and improve soil structure so that Na^+ can be leached. Gypsum ($CaSO_4$) is the most common amendment and may be used in acidic or alkaline soils; it will not change the soil pH. Lime may also be added and would raise the pH of an acidic soil. If soil contains "free lime", (calcium carbonate, $CaCO_3$), then adding an acid, like sulfuric acid (H_2SO_4), will liberate the Ca^{2+} in the soil to form gypsum. Free lime may be present in alkaline soils. The following are considerations with adding soil amendments: 1) If soil infiltration is already good, then applying a calcium amendment might not be economical; 2) The amount of amendment depends on the amount of exchangeable Na^+ in the soil and could be costly; 3) The process can be slow because amendments must solubilize and react in the soil; and 4) Soil amendments do not eliminate the need for leaching.

Leaching

The primary management strategy for combating salinity is leaching, and leaching must be practiced when soil salinity has the potential to impact crop yield. Leaching occurs when water is applied in excess of soil moisture depletion due to evapotranspiration (ET). The leaching fraction (Lf) is the fraction of the total applied water that passes below the root zone. The leaching requirement (Lr) is the minimum amount of the total applied water that must pass through the root zone to prevent a reduction in crop yield from excess salts. In other words, the leaching requirement takes into consideration the crop salinity thresholds beyond which yield declines are expected. Leaching may occur during the rainy season or whenever an irrigation event occurs; however, leaching during the season may not be advisable because nutrients (like nitrogen) may be lost from the system.

Examples from Cropping Systems in the Sacramento-San Joaquin Delta

The Sacramento-San Joaquin River Delta region – for its soil type, climate, and water sources – is a unique agricultural region of California. Diverse crops grow in the Delta region, and alfalfa, processing tomatoes, and vineyards have accounted for approximately 30 percent of the agricultural acreage in recent years (Medellin-Azuara et al., 2016). Surface water from Delta channels is used for irrigation, and water quality (i.e. salinity) can vary over the year based on river flows, and daily based on sea water intrusion from ocean tides. Research project results illustrate the challenges associated with leaching salts under various cropping systems and irrigation methods in the Delta but suggest strategies for alleviating salty conditions under these conditions.

In a multi-year study (2013-2015) of drip-irrigated processing tomatoes (Aegerter and Leinfelder-Miles, 2016), leaching was observed to occur laterally away from the buried drip emitters (Fig. 1). This is similar to the results observed by Hanson and May (2011) in drip-irrigated cropping systems in the San Joaquin Valley. Salts concentrated in the top 10 cm (4 in) of soil and at about 90 cm (3 ft) below the surface, where fine-textured organic matter likely impeded downward water movement. Average root zone salinity worsened from 0.8 dS/m in Spring 2013 to 1.3 dS/m in Fall 2015. Even at 1.3 dS/m, the average root zone salinity was below the threshold at which yield declines are expected for processing tomato (2.5 dS/m; Ayers and Westcot, 1985). Nevertheless, rainfall was not sufficient in these drought years to leach salts during the winter seasons. Salts that are not leached may be redistributed in the profile and impact future cropping.

Electrical Conductivity, ECe (dS/m)

Spring 2013

Depth (cm)	Bed Center ↓			Furrow ↓
0 - 10	0.84	0.74	1.24	
10 - 20	0.93	0.84	0.75	0.72
20 - 30	0.81	0.84	0.92	0.74
30 - 40	0.94	0.84	0.73	0.76
40 - 50	0.67	0.92	0.74	0.79
50 - 60	0.64	0.76	0.74	0.79
60 - 70	0.68	0.79	0.75	0.71
70 - 80	0.82	0.77	0.79	0.71
80 - 90	0.83	0.77	0.74	0.73
90 - 100	0.81	0.80	0.78	0.66

Fall 2015

Depth (cm)	Bed Center ↓							Furrow ↓
0 - 10	2.50	2.51	2.97	2.34	2.67	2.27	2.76	2.69
10 - 20	1.37	1.17	1.12	1.02	1.05	0.96	2.51	4.49
20 - 30	0.85	0.85	0.85	0.86	0.90	1.08	0.81	1.04
30 - 40	0.87	0.94	0.99	0.92	0.95	0.87	0.74	0.76
40 - 50	1.12	0.89	1.26	1.15	0.99	0.86	0.85	0.71
50 - 60	1.06	1.05	1.37	1.08	0.89	0.84	0.61	0.71
60 - 70	0.94	0.96	1.52	1.16	1.09	0.88	0.71	0.87
70 - 80	0.83	0.94	1.32	1.49	1.21	1.11	1.01	0.87
80 - 90	1.15	1.17	1.46	1.51	1.58	1.56	1.43	1.21
90 - 100	1.47	1.75	1.66	1.68	1.67	1.68	1.68	1.51

Legend* 2.5 3.5 5.0 7.6 13.0

Figure 1. Soil salinity (ECe, dS/m) of drip-irrigated tomato beds in Spring 2013 and Fall 2015. The year 2013 was the first year of drip irrigation in this field. Salts accumulated in the root zone over these three years of drought, and average root zone salinity worsened from 0.8 dS/m to 1.3 dS/m. Localized leaching occurred near the drip tape and laterally from the drip tape toward the furrow. Legend from Ayers and Westcot (1985) indicates the salinity at which 100, 90, 75, 50, and 0 percent yield potential is expected for tomatoes.

Over the same three-year period, the soil salinity profile and leaching fraction was evaluated in seven border check flood irrigated alfalfa fields. These sites varied in soil type, water quality, and groundwater depth, and results illustrate how inherent site properties influenced soil salinity profiles. Across these seven sites and three years, average root zone salinity ranged from 0.71 dS/m to 7.18 dS/m. At only two sites was an average root zone salinity below 2.0 dS/m maintained across the study period, the level at which 100 percent yield potential is expected for alfalfa. Some of the study sites likely accumulated salts because shallow groundwater impeded salts from leaching out of the root zone or low permeability soil impaired leaching. At a site with a higher permeability soil (fine sandy loam), soil salinity profiles indicate that perhaps irrigation could have been managed differently to achieve better leaching and lower soil salinity. At this site (Fig. 2), leaching was better on the top end of the border check than on the middle and bottom sections of the field. If irrigation water had a longer opportunity time for infiltration on the lower end of the field, this might have reduced salinity in the soil profile. This practice would have to be carefully monitored, however, to ensure that water does not sit on the field and result in root rot diseases. A different site, also with a fine sandy loam, showed that a high leaching fraction could be achieved, and even with high salinity irrigation water, a high leaching fraction maintained average root zone soil salinity below the crop tolerance level for alfalfa.

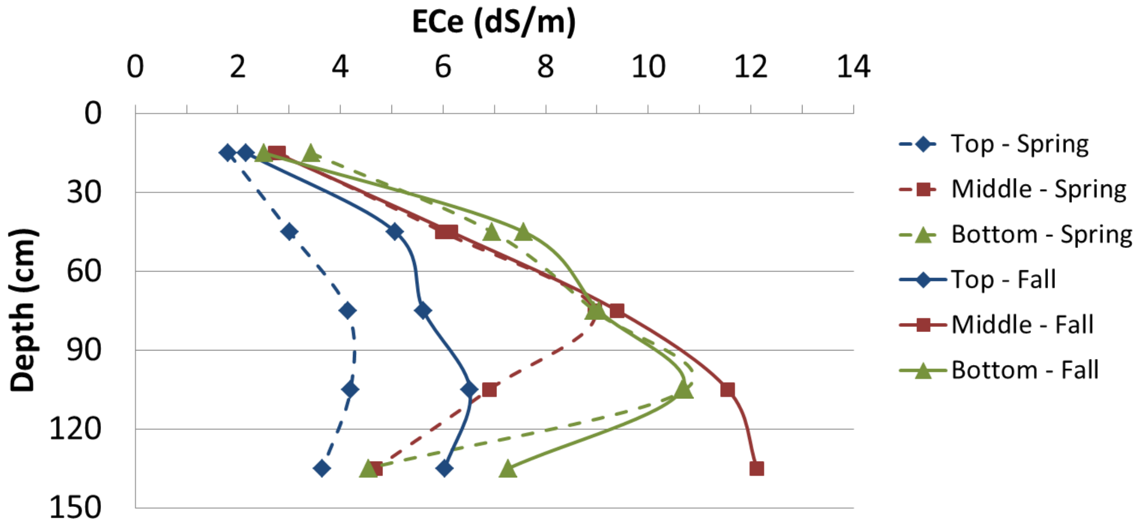

Figure 2. Soil salinity profile of a border check flood irrigated alfalfa field from the soil surface to a depth of 150 cm (approx. 5 ft) in the Spring and Fall 2014. Salinity was higher in the middle and bottom sections of the field compared to the top section of the field, indicating that the longer opportunity time on the top end of the field provided better leaching.

Finally, in a drip-irrigated vineyard, the soil salinity profile was characterized in a one-time soil sampling in August 2016. Similar to the aforementioned drip-irrigated tomatoes, the wetting pattern appeared to push salts away from the drip tape to approximately 120 cm from the vine row and 120 cm deep. This region of the soil profile had some of the highest salinity (Fig. 3). The saturation percentage (SP) at this depth was approximately 90 percent. The SP of a soil correlates well with soil texture, and when the SP ranges from 65-135 percent, the soil is characterized as clay (Neya et al., 1978). Clays, as fine textured soils, have low permeability; thus, the salts appeared to be accumulating at the depth where infiltration was inhibited by inherent soil characteristics. The average root zone salinity was approximately 3.3 dS/m. The soil salinity threshold for grapes is 1.5 dS/m, beyond which yield declines are expected. Thus, there was the potential for salinity to impact yield at this vineyard.

Grapes, South - Electrical Conductivity (ECe, dS/m)

Depth	Vine Row 0 cm ↓	30 cm	60 cm	90 cm	Alley Center 120 cm ↓
0 - 30		1.20	2.19	3.57	2.18
30 - 60		1.06	2.15	3.57	2.61
60 - 90		3.03	2.94	4.44	5.18
90 - 120		3.82	4.15	4.90	5.35
120 - 150		2.30	1.88	2.79	2.49

Legend*				
1.50	2.50	4.10	6.70	12.00

Grapes, South - Saturation Percentage

Depth (cm)	Vine Row 0 ↓	30 cm	60 cm	90 cm	Alley Center 120 cm ↓
0 - 30		0.66	0.69	0.66	0.67
30 - 60		0.84	0.82	0.83	0.79
60 - 90		0.91	0.98	0.96	0.94
90 - 120		0.89	1.00	0.95	0.90
120 - 150		1.02	1.08	0.98	1.00

Figure 3. Soil salinity profile (ECe, dS/m) and saturation percentage (SP) profile of drip-irrigated vineyard soil. Salts appeared to accumulate approximately 120 cm (4 ft) below the soil surface where the SP indicated fine-textured/low permeability soil. Average root zone salinity was 3.3 dS/m. Legend from Ayers and Westcot (1985) indicates the salinity at which 100, 90, 75, 50, and 0 percent yield potential is expected for grapes.

In all three of these research projects, results indicate that more leaching is needed to avoid impacts to crop production because other management strategies would have limited impact or relevance. Soil amendments would likely not be helpful in these Delta soils that are usually acidic, and with the possible exception of alfalfa, salt tolerant varieties are not available or desirable. It is not always possible (or desirable) to apply enough water to leach salts during the growing season. In the Delta, low soil permeability soils or proximity of groundwater are inherent site characteristics that may inhibit leaching. Agronomic considerations, like disease prevention or fruit quality management, are considerations across agricultural systems and regions. Low winter rainfall may mean that leaching during the off-season is inadequate. All of these conditions put constraints on growers' ability to manage salts; however, growers may be able to enhance leaching during the off-season by leveraging rainfall with irrigation water to wet the soil profile before a rain event. For the Delta, maintaining water quality salinity objectives will also be important for maintaining soil quality and crop yields.

Summary

Salinity affects agriculture in arid climates throughout the world, impacting crop productivity and degrading soil resources. It is important to monitor irrigation water and soil salinity in cropping systems to understand baseline conditions and changes over time. Strategies for managing salinity include site selection, variety selection, soil amendments, and leaching. Growers should consider the salinity condition before a crop is planted by testing the soil and water, leaching salts, and managing irrigation for the most vulnerable crop stage (seedling/young trees or vines). Variety selection and soil amendments may help mitigate a salinity condition, but these do not eliminate the need for leaching. Leaching is the primary means of managing salinity and must be practiced when there is the potential for salinity to impact crop yield. The Sacramento-San Joaquin River Delta is an agricultural region that is impacted by salinity due to its soil types, climate, and irrigation and groundwater sources. Research results from the Delta illustrate the challenges associated with leaching in these cropping systems but suggest strategies for alleviating salty conditions.

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