Managing Drought, Salinity, and Crop Nutrition

In California, there are no miracle cures. Leaching is only remedy when using saline irrigation water.

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***Summary:** The last word of advice is to avoid miracle cures. There are none. Aside from reverse osmosis, there are no magic elixirs, magnets, ionizers or other devises that remove salt from irrigation water. The only remedy for continued use of saline irrigation water is leaching. Having your soil properly conditioned to take advantage of winter rains by treating the soil with calcium and high bicarbonate irrigation water with an acid will set the stage for effective leaching when winter rains arrive.*

There are two four-letter words Californians just can't seem to get enough of: rain and snow. For a third consecutive year, sub-adequate rainfall and, more importantly, scant Sierra snowpack have left the state's storage reservoirs at just 53 percent of capacity statewide. And with the Sierra snowpack at just 16 percent of normal, the opportunity to further raise lake levels significantly through spring and summer melt is dim to nonexistent.

Drought status

California's water supply is very short and must be balanced to meet the competing needs of cities, the environment, and agriculture. Federal and state surface water deliveries to the thirsty San Joaquin Valley, slashed originally at 0 percent, have been upgraded to a less than impressive 5 percent of normal. The impacts will be far reaching with an estimated 500,000 to 800,000 acres of irrigated farmland looking for alternative water sources. Many acres of row crops, such as cotton, melons, vegetables, field corn, etc., will simply remain idle. Cotton acres, for example, are expected to be at their lowest levels since pre-Depression days--just 190,000 acres. This is down about 100,000 acres from 2013. Growers of increasingly popular perennial crops, such as almonds and pistachios, are bracing for lower yields and reduced profits. Others are hoping they have or can find enough water to keep their orchards alive and their investments solvent. The economic ripple will impact all industries and services that support and supply producers and those that transport, process, and market Ag commodities. Consumers can expect to pay more for food in the near future. Unemployment in farming communities greatly outpaces the state average. Tax revenues will fall from decreased farm gate proceeds and the industry that supports farming will be in decline. Few will likely be spared.

As surface water availability decreases, growers are becoming more reliant on California's massive groundwater reserves to meet production needs. But over-drafting of groundwater is a serious concern. The consequences are being felt now and will only become more acute in future years if current trends continue. One consequence of over-drafting ground water that is very troubling is a sinking of the Valley floor. An estimated 50 million acre-feet of ground water has been pumped and not recharged since 1962. As aquifers dry, ground sinks, and with their sinking, the very conveyance systems designed and built to deliver irrigation water during the arid summer months are at risk of failure.

Salinity

There is another danger that lurks with reliance on ground waters. Salinity. Much of the ground water in the Central Valley contains very high levels of dissolved salts, particularly in the west side of the San Joaquin Valley. Also, as groundwater levels in California's coastal valleys drop, salt water intrusion threatens to seriously degrade the quality of these water resources. As more salty water is applied to farmland and less water is available for leaching harmful salts out of the root zone, the risk of crop injury and economic loss to the producer grows. Continued use of saline irrigation water without proper leaching jeopardizes the sustainability of hundreds of thousands of acres of California farmland (Figure 1).

To illustrate just how rapidly soil salts can accumulate in the absence of leaching, consider that water having an ECw of just 1.0 dS/m (low), applied at 3 acre-feet annually, would add more than 50,000 lbs of salt per acre over a ten-year period! Thus, without adequate leaching, even waters of moderate quality can rapidly build the soil's salts to disastrous levels.

By definition, a saline soil is one that has an Electrical Conductivity of the soil extract (ECe) greater than 4.0 dS/m. Soil salinity levels above or below 4.0 may or may not be injurious to crops, so it is more important to know the salt tolerance of crops to be grown rather than what defines a saline soil. Table 1 presents salt tolerance data for some crops grown in California. Data are presented as the ECe (soil) and the ECw (water) that would be expected to cause yield losses of 10, 25, and 50 percent or complete crop loss as well as the maximum salinity levels for unhindered crop yield. This assumes a

Figure 1. Visible salt accumulation will become a more common site in California as grower's reliance on salty ground water increases.

leaching fraction of 15 percent.

More complete crop salinity tolerance data can be found in the Western Fertilizer Handbook produced by the Western Plant Health Association, Sacramento, CA available at http://www.waveland.com/browse.php?t=17&r=a|728

Under normal irrigation practices, the ECe should be about 1.5 times that of the ECw. When the ECe exceeds about 3 times that of ECw, then insufficient water is passing through the root zone to leach salts. This may be due to either sub-adequate amounts of irrigation water and rainfall or a subsoil condition such as a hardpan or another restrictive layer that is preventing deeper percolation of water. Periodic assessment of both water and soil salinity provides very useful information to growers and crop consultants and should be standard procedure, particularly for new wells or where salts are known to be a concern.

There are two basic processes by which salts harm plants:

- Osmotic potential or stress
- Specific ion toxicity.

Osmotic stress is likely the dominant cause of salt-induced yield and growth reductions in most situations. In a non-saline soil, the concentration of ions internal to the plant is higher than the one external to the plant. This allows for osmosis--the passive diffusion of water from an area of lower salt content to an area of higher salt content. As soils become saltier, the difference in salt content between the plants and the soil narrows, which slows the rate of osmosis. This is called osmotic stress, which makes water less available to plants. Plants respond by either taking in more ions (salts) to raise the salt content in the roots or by synthesizing more sugars or organic acids, which has the same effect as absorbing more salt ions. Both processes require energy that would otherwise be used for growth and yield. Eventually, when the concentrations of ions in the soil exceed the concentration of ions in the plant, osmosis stops and plants wilt, collapse, and die. In essence, the soil is physically wet but physiologically dry. Osmotic stress can greatly stunt plants without plants developing visual necrosis symptoms common to specific ion toxicity as can be seen in Figure 2.

Specific ion toxicity pertains to the accumulation of sodium, chloride, or boron to levels that cause cellular death. Whereas sodium and chloride also can be dominant ions contributing to total salinity, boron concentrations are typically in the single digit ppm range and therefore have no effect on soil salinity. Specific ion toxicities cause leaf chlorosis and necrosis and leaf drop (in milder cases), and collapse

Table 1: Drought, Salinity and Crop Nutrition: Interactions and Management.

	0%		10%		25%		50%		100%
Crop	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Alfalfa	2	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16
Almond	1.5	1	2	1.4	2.8	1.9	4.1	2.7	6.8
Brocolli	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14
Corn	1.7	1.7	2.5	1.7	3.8	2.5	5.9	3.9	10
Cotton	7.7	5.1	9.6	6.4	13	8.4	17	12	27
Grape	1.5	1	2.5	1.7	4.1	2.7	6.7	4.5	12
Lettuce	1.3	0.9	2.1	1.4	3.23	2.1	5.1	3.4	9
Rice	3	2	3.8	2.6	5.1	3.4	7.2	4.8	11
Tomato	2.5	1.7	3.5	2.3	5	3.4	7.6	5	13

Adapted from Quality of Water for Irrigation. R. S. Ayers, Journ. Of the Irrig. And Drain.Div. ASCE. Vol. 103, No. IR2, June 1977, R140, and Salt Tolerance of Plants, E. V. Maas. Appl. Agri. Res.Vol. 1, No. 1, 1986

Note: On gypsiferous soils ECe readings may be as much as 2 dS/m higher on the laboratory report than under actual field conditions.

of entire plants or limbs and scaffolds in tree crops in extreme cases.

Sodium further complicates salinity issues due to its role in degrading soil structure. As sodium is added to the soil via irrigation water, it can gradually replace calcium on the exchange complex. As exchangeable sodium rises, soil aggregation and structure decrease. This degradation of soil structure leads to decreases in aeration, water infiltration, and percolation. Irrigation water that contains high levels of both sodium and bicarbonate is particularly troublesome. As soils dry between irrigations, bicarbonate (HCO_3) combines with calcium ions forming insoluble limestone (calcium carbonate). Calcium ions displaced from the exchange complex may be replaced with sodium. In this manner, a calcium dominant soil can become a sodium dominant soil. Once the Exchangeable Sodium Percent (ESP) reaches 15, the soil is classified as a Sodic soil. But as with Saline soil, crop damage may occur well below this threshold--as low as an ESP of 5 for some sensitive crops. Key to this discussion is that sodium dominant soils do not drain well and, therefore, are an impediment to leaching of salts. As will be discussed later, a key component of managing water and soil salinity/sodicity in years of low irrigation and rainfall is to minimize the effects of both sodium and bicarbonate.

A comprehensive guide to chloride, sodium, and boron tolerances can be found at http://www.fao.org/docrep/003/T0234E/T0234E05.htm Water Quality for Agriculture.

Interactions. It is beyond the scope of this article to adequately address nutrient–salinity interactions due to the extreme complexity of the topic. An excellent review of the subject matter is presented by Grattan and Grief at http://ag.wilburellis.com/Products/Documents/salinity%20nutrient%20interactions.pdf

Though research on nutrient-salinity interactions often provides contradictory results due to differences in protocol (field vs. pot or solution culture, single vs. mixed salts, plant species, duration of the study, etc), it is clear that plant growth and performance may be negatively affected by salinity-nutrient interactions. It is interesting to note that there is little empirical evidence that the addition of nutrients beyond that considered adequate or optimal for growth has any benefit in a saline environment.

Calcium may be the exception to this generalization. For crops known to be sensitive to calcium related disorders, the effects are often exaggerated under saline conditions. As soil salinity

Figure 2. Improperly spaced subsurface drainage resulted in non-uniform leaching of soil salts leading to extreme stunting in the saltier areas of the field. Note the lack of overt salt toxicity symptoms in the stunted plants. ECe in the non-affected area was 0.5 dS/m and 5-8 dS/m in the affected areas.

increases, crop requirements for calcium also increase and at the same time calcium uptake may be suppressed (competition with sodium, precipitation). Supplemental calcium applied under saline conditions has been shown to lessen specific ion toxicities, reverse some of the negative effects of salinity, and even improve yield and marketability of some crops. Thus, calcium may be an important tool to help producers minimize the deleterious effects of salinity even in a low moisture environment.

Gypsum (calcium sulfate dehydrate), limestone (calcium carbonate), dolomitic limestone (calcium magnesium carbonate), and various calcium containing fertilizers are common sources of soil-applied calcium. Gypsum offers the greatest flexibility as it will provide soluble calcium at any soil pH whereas the carbonate sources require an acid soil pH to release soluble calcium ions. Elemental sulfur upon conversion to sulfuric acid by soil bacteria can be a very economical source of calcium provided the treated soil contains free limestone. A simple “fizz test” can be used to make this determination in the field by pouring an acid (vinegar will work) on soil and observing for effervescence or bubbling. This is CO_2 being evolved as the acid digests limestone. Lack of fizzing means lack of adequate levels of limestone to use elemental sulfur for this purpose.

Supplemental calcium may not only act to relieve crops of some of the negative effects of salinity and specific ion toxicity, but also benefits soil structure, which leads to optimal leaching when potential rainfall or leaching irrigations occur.

Treating high bicarbonate irrigation water with an acid such as urea sulfuric acid to digest a portion of the bicarbonate is another management strategy when using saline waters, particularly if they also contain appreciable levels of sodium.

$H+ \ + \ HCO_3$ ------------> $H_20 \ + \ CO_2$

As mentioned earlier, bicarbonate forms limestone when soils dry between irrigations. This may reduce both soluble and exchangeable calcium levels. As calcium is stripped from the exchange sites by this reaction, a negative charge remains, which will attract other cations such as sodium. Digesting a portion of the bicarbonate slows this process and is another strategy that can be used to maximize soluble and exchangeable calcium levels in the soil. As a general rule of thumb, acidifying the water to a pH of 6.0 consumes roughly 50 percent of the bicarbonate content of the irrigation water.

Last word

The last word of advice is to avoid miracle cures. There are none. Aside from reverse osmosis, there are no magic elixirs, magnets, ionizers, or other devices that remove salt from irrigation water. The only remedy for continued use of saline irrigation water is leaching.Having your soil properly conditioned to take advantage of winter rains by treating the soil with calcium and high bicarbonate irrigation water with an acid will set the stage for effective leaching when winter rains arrive.

For information on deficit irrigation strategies and other drought related topics go to http://ciwr.ucanr.edu/California Drought Expertise/Drought information/

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