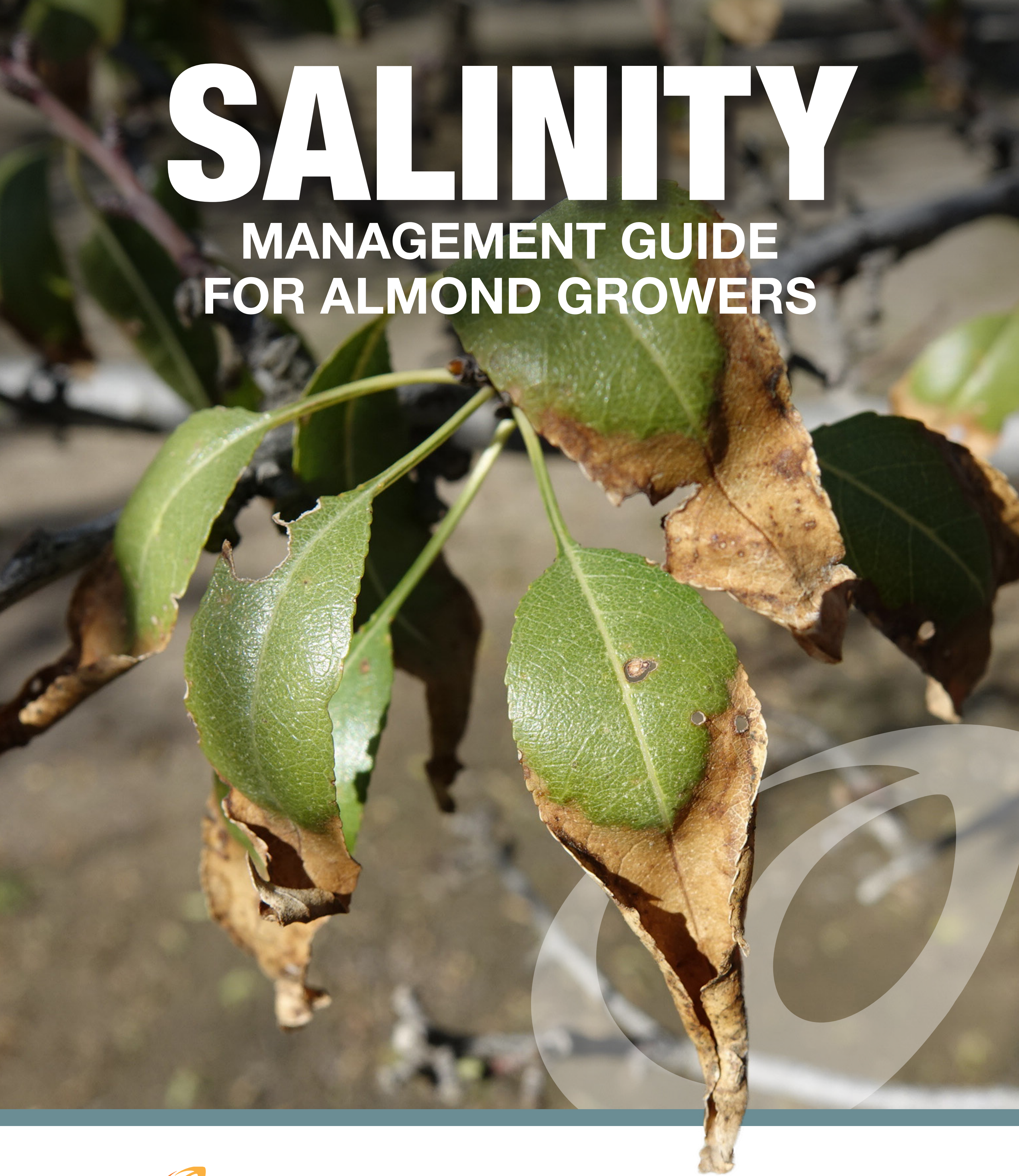
SALINITY

MANAGEMENT GUIDE FOR ALMOND GROWERS



California almonds
Almond Board of California

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ABC SALINITY MANAGEMENT

Almond trees are most productive on non-saline, deep, well-drained soil. However, many orchards across California are located in 'salt-affected' areas and require specific soil and water management approaches to prevent or mitigate salt problems and ensure continued almond tree viability and productivity. Salt-affected or "saline" soils occur naturally in many almond-producing areas, but degrading water quality, decreasing water availability, drainage issues, drought, and in some areas, seawater intrusion, are increasing salinization problems broadly. The composition of tree-damaging salts varies across different agricultural areas, but problems commonly result when high levels of sodium (Na), chloride (Cl), boron (B), and bicarbonate (HCO_3) are present in the soil and or water alone or in combination with each other.

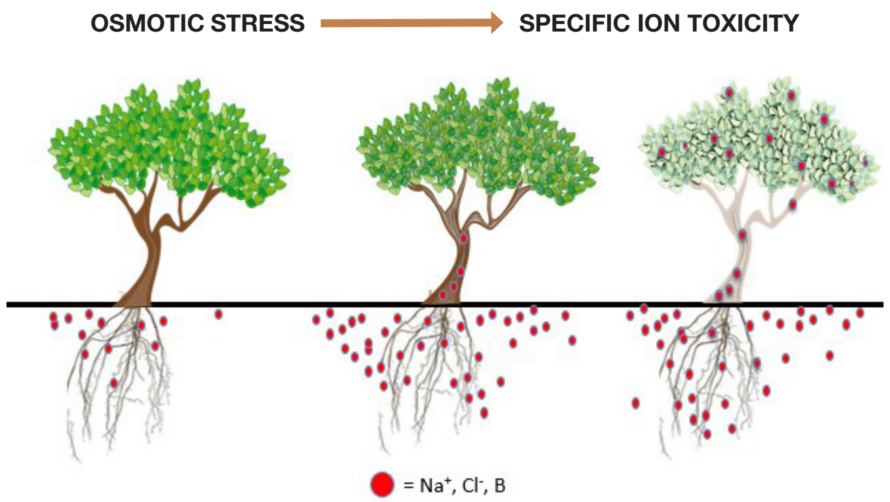


FIGURE 1

Almond trees' response to elevated salinity begins with osmotic stress and dehydration; eventually, tree roots will no longer be able to exclude increasing concentrations of salt, accumulating toxic levels of salt ions in the trunk, scaffolds and leaf tissues. Diagram M. Culumber

SALINITY IMPACT ON ALMOND TREES

The harmful impacts of salt can develop early in orchard establishment, resulting in water stress, nutrient imbalances and in the long run stunted trees. When initially exposed to saline conditions, trees experience osmotic stress, making trees effectively work harder to take up water and nutrients (Figure 1). In these circumstances, trees are experiencing salt-induced drought stress despite adequately moist soil conditions. Inadequate water uptake reduces turgor pressure in the cells that regulate stomatal pore opening causing them to close partially. Closure for prolonged periods of time can increase leaf temperature, decrease gas exchange, and impair cellular function. If these conditions persist over time, salt ions in the soil water surrounding the roots will eventually reach concentrations the tree can no longer exclude, allowing salts to accumulate in the woody tissue and canopy (Figure 1). On a dry leaf basis, July concentrations of 0.3% Cl and 0.25% Na are considered toxic. Salt uptake forms necrotic tissue injuries at the tips or margins of leaves (Figure 2), or across the entire leaf surface area, which reduces photosynthesis and leads to premature defoliation. Over time, inadequate shoot growth, reduced crop kernel size and shrivel can result. Once trees reach this stage, it can take extensive soil mitigation efforts over several seasons to restore the health and productive potential of the almond orchard.

FIGURE 2

Necrotic almond tree leaves with toxic sodium levels and deficient potassium levels confirmed by laboratory analysis. Photo: M. Culumber.

WHAT IS SALINITY?

Salinity is most simply described as the total concentration of dissolved salts in irrigation water or the soil. Electrical conductivity (EC) is a measure of total dissolved salts in irrigation water or soil water commonly reported in units of deci-Siemens per meter (dS/m) or millimhos per centimeter (mmhos/cm). Soil and irrigation water EC provides a means to evaluate the potential for salt-induced stress on tree growth and decreased productivity. Almond is a very salt sensitive species and yield declines have been observed at EC levels above 1.5 dS/m, and irrigation water levels above 1.1 dS/m (Table 1). The general rule of thumb is a 15% decline in yield for every 1.0 dS/m increase in EC (Maas, 1990).

	Percent of Full Yield Potential		
Salinity measurement (in dS/m)	100	99 – 40	< 40
Average root zone	< 1.5	1.5 – 4.8	> 4.8
Irrigation water	< 1.1	1.1 – 3.2	> 3.2

TABLE 1

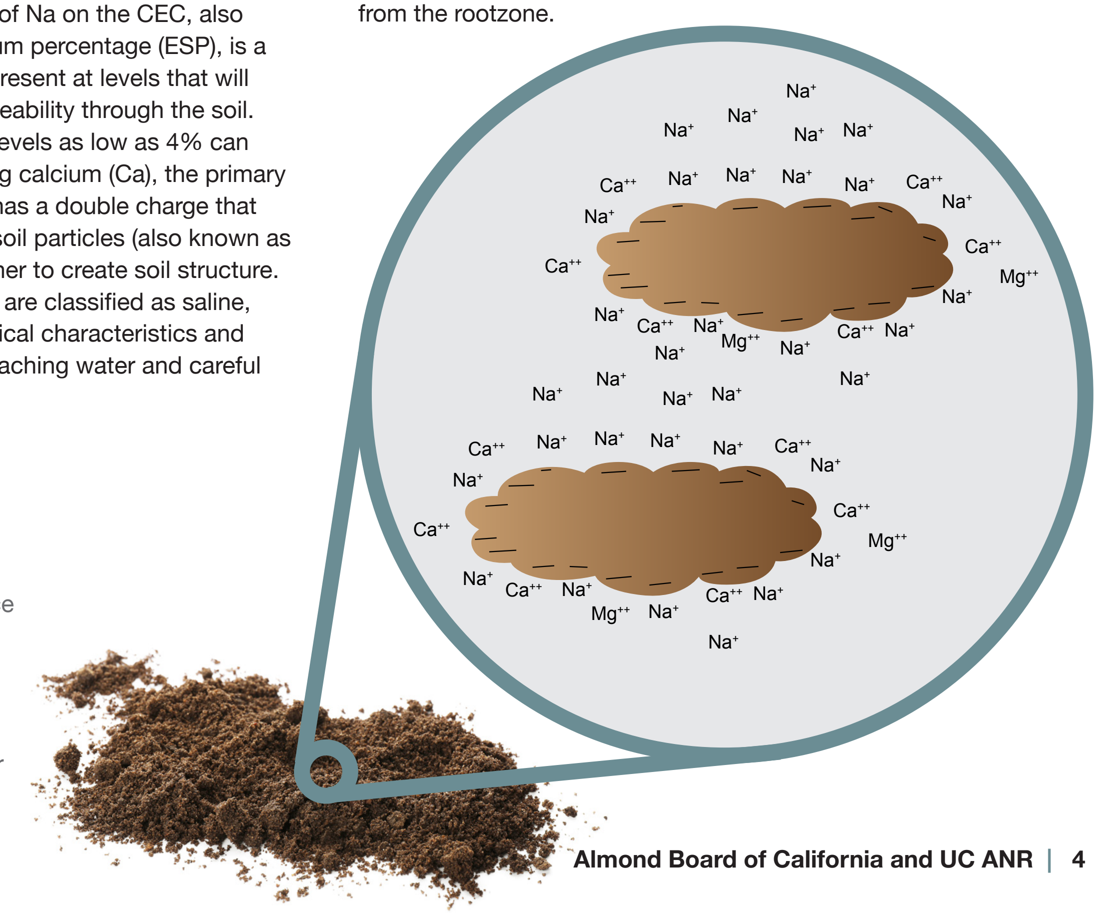
Estimated impact of increasing salinity (dS/m) in the soil rootzone and in irrigation water on almond yield potential. Adapted from Maas (1990) p. 280

SODIUM

In addition to overall EC levels, salt composition impacts the severity of salinity-induced yield reduction. Sodium (Na) is the most problematic salt because in addition to the osmotic stress and direct root contact toxicity, high concentrations also degrade soil structure. Soil particles have many negative charges on their surface that attract positively charged cations mainly Ca, Mg, K, and Na. Cation exchange capacity (CEC) is a measure of the ability of a soil to retain cations. The percentage of Na on the CEC, also known as the exchangeable sodium percentage (ESP), is a measure used to predict if Na is present at levels that will reduce water infiltration and permeability through the soil. Depending on the soil type, ESP levels as low as 4% can destroy soil structure by displacing calcium (Ca), the primary ion for soil stabilization. Calcium has a double charge that attracts the surfaces of adjacent soil particles (also known as colloids), which holds them together to create soil structure. Soil with high levels of Na and Ca are classified as saline, but generally have good soil physical characteristics and can be managed with sufficient leaching water and careful fertility management. However, when Na greatly exceeds Ca and magnesium (Mg) levels (Figure 3), Na ions weaken the bonds holding soil colloids together, causing them to disperse easily with irrigation or precipitation. This loss in soil structure reduces drainage and creates low oxygen conditions that will compound tree root stress. Excessive Na levels in soil and water can be reclaimed with amendments that supply Ca to improve soil structure and increase the ability to leach salts from the rootzone.

FIGURE 3

Excessive levels of Na will displace Ca and Mg on the negatively charged surfaces of soil colloids, weakening the bonds between soil particles and degrading soil structure. Illustration M. Culumber



BICARBONATES

Bicarbonates (HCO_3) themselves are not toxic to almond trees but at elevated levels (>1.5 meq/L) can complex with Ca and Mg, leaving Na to dominate the CEC creating soil water infiltration problems. When HCO_3 precipitates with Ca and Mg, calcium carbonate (lime) is formed, which appears as a white chalky substance on the soil surface and microirrigation emitters, a major source of clogging when not amended properly (refer to back cover photo for a visual example). When calcium carbonate is dissolved with water, the reaction forms hydroxyl ions that can drive up soil pH levels, further limiting nutrient availability. Bicarbonate also complexes with other nutrients including Fe and Zn restricting uptake by almond trees (Figure 4).

PH

pH is a measure of acidity or alkalinity in irrigation water or in the soil. The natural pH range for irrigation water is typically between 6.5 to 8.4, with a pH above 7.0 considered alkaline, and below 7.0, acidic. Extreme acidity (pH < 5.0) or alkalinity (>8.4) can have negative impacts on the soil, plants, and irrigation system components. Over time irrigation water pH can influence the soil pH, and lead to nutrient imbalances and accumulations of toxic ions in almonds. High pH irrigation water accompanied by elevated Ca, Mg, or HCO_3 will precipitate to form Ca and Mg carbonates that when dissolved can further increase soil pH and decrease the solubility of nutrients. Levels above pH 7.5 limits the availability of many essential elements, in particular micronutrients iron (Fe), zinc (Zn), manganese (Mn), and B (Figure 4). Some almond rootstocks including Nemaguard, Lovell, and Guardian are very susceptible to lime induced chlorosis (Micke, W.C. (1996)- Duncan and Edstrom chapter)

FIGURE 4

Irrigation water with high pH or high HCO_3- reduces the solubility of nutrients. Some nutrient deficiencies, particularly Fe and Zn deficiencies, are characterized by pattern of interveinal yellowing in the leaf tissues of young leaves. Photo M. Culumber

BORON

Boron
B
10.81 5

Boron is an uncharged trace element that does not contribute to measured EC but often occurs in soil environments characterized by salinity. Boron is an essential element but elevated levels in soil and water, > 1.5 ppm, can lead to toxicity resulting in shoot die-back, as well as nut gumming and sticking to the tree. The critical threshold for B in the leaf tissues are not clearly established, and hull samples should be used instead. Hulls are the primary sink for B and levels between 100 to 160 ppm are considered sufficient, while values lower than 80 ppm are considered deficient for tree productivity. Hull B levels higher than 200 ppm are in the toxicity range. Boron ions strongly hold (adsorb) to soil particles at higher pH levels typical of saline soils, and acid amendments with ample water are necessary to flush excess B out of the rootzone and keep hull values in the adequate range.

CHLORIDE

Chlorine
Cl
35.45 17

Chloride is a common constituent in saline soils and irrigation water. Elevated levels (> 8 meq/L in soil extract) reduce the tree's ability to take up water and are toxic to roots and leaf tissues. Chloride is very mobile in soil and easily leached from most soils with a winter soil reclamation program, assuming good drainage.

WATCH NOW
Almond Rootstock Trial: Boron Tolerance Field Notes Video

SOIL TYPE

Clay soils throughout the Central Valley are comprised of minerals that tend to drastically shrink and swell in response to soil wetting and drying cycles. These soils are particularly sensitive to Na accumulation at ESP levels as low as 4%. Sandy soils have fewer soil CEC sites that can be quickly overwhelmed by salt ions, leading trees to experience osmotic stress or toxicity at lower salt concentrations than found in clay soils. Highly saline conditions, particularly in sandy soils, can lead to deficiencies of calcium (Ca), potassium (K), nitrate-nitrogen ($N\text{-}NO_3$), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu), and phosphorus (P). Fortunately, sandy soils can be reclaimed each season with adequate amounts of leaching water.

ROOTSTOCK PERFORMANCE UNDER SALINE CONDITIONS

Choosing the appropriate rootstock for different soil conditions, including saline areas, is important for maintaining healthy, productive trees through the life of an orchard. Standard rootstocks — Nemaguard, Lovell, Guardian and Krymsk 86 — commonly experience micronutrient deficiencies, leaf chlorosis, stunted shoot growth, and lower yield on soil with high pH and elevated salt levels. UC research trials identified peach x almond hybrid rootstocks including Hansen 536, Cornerstone, Brights 5, BB 106, FxA, Nickels, and GF 677 to have better adaptability for saline and alkaline conditions with greater size and higher cumulative yield than rootstocks with peach genetics (Duncan, ABC report 2022). Some proprietary clones of Titan hybrid rootstocks have not been as extensively tested as other peach x almond hybrids, but field observations suggest they are also good at excluding Na and Cl. Rootpac R (plum x almond) has been shown to efficiently exclude Cl, but can accumulate damaging levels of Na. Empyrean 1 (*P. davidiana* peach hybrid) and Viking (complex hybrid) rootstocks do not perform as well as the peach x almond hybrids, but are more salt and ring nematode tolerant than Nemaguard.

Rootstock salinity tolerance and other characteristics

Scan the QR code or visit https://bit.ly/3owcGnn

SOIL AND IRRIGATION WATER AMENDMENTS

The purpose of applying amendments is to provide a source of Ca to replace the Na and remove it from the rootzone. There are two main types of amendments: calcium supplying amendments and acid amendments. Some of the most common materials can be found in Table 2 on page 7. Gypsum is a Ca supplying material valued for its moderately slow release of soluble Ca to continually improve infiltration and provide a source of plant nutrients. Acidifying products react with Ca bound by HCO_3 or soil lime ($CaCO_3$) to form gypsum. The sulfate in gypsum binds with Na to easily leach it from the soil, while Ca takes its place on the surface of soil particles. A large quantity of Ca is usually needed to displace Na and a combination of both calcium supplying and acid amendments can be beneficial. Yet, because amendments add salts to the soil, too much at once can add to the osmotic stress that limits water uptake by trees. The decision to apply materials to soil or irrigation water should be based on laboratory analyses that reveal the severity and depth of the salt problem.

Lab analyses will provide concentrations on a weight or volume basis. Parts per million (ppm), percent %, and in milligrams per kilogram (mg/kg) are weight-based, while milligrams per liter (mg/l), milliequivalents per liter (meq/l) represent concentrations by volume.

SOIL AMENDMENTS

If soil tests reveal Na loads are high throughout the rootzone, soil amendments applied after harvest followed by adequate leaching may be needed to reclaim the soil before the next growing season. Determining the right rate of soil applied Ca amendments to displace Na requires knowing the **cation exchange capacity (CEC),** and the **exchangeable sodium percentage (ESP),** the portion of Na cations that occupy the CEC. From a soil analysis, use the total CEC and ESP (also known as Na % base saturation on some reports) to calculate the tons per ac foot material needed to displace Na and reduce the ESP to less than 4%. The calculations are in meq/100 g units since 1 meq of Ca equals 1 meq Na in terms of chemical equivalency.

Example to calculate the tons per acre foot of material needed to displace Na and reduce ESP:

From a soil test analysis:
CEC = 60 (meq/100 g soil)
ESP % = 9.3

STEP 1

Calculate the initial exchangeable Na (meq/100g)

Initial exchangeable Na (meq/100 g) = (initial ESP × CEC)/100

Initial exchangeable Na = (9.3 × 60 meq/100 g)/100 = 5.6 meq Na/100 g

STEP 2

Calculate the exchangeable Na (in meq/100 g soil units) that needs replacement to attain the desired final 4% ESP.

Final exchangeable sodium = (final ESP× CEC)/100

Final exchangeable Na = (4 × 60 meq/100 g soil)/100 = 2.4 meq Na/100 g

STEP 3

Calculate the Ca requirement (in meq/100 g) to reduce Na to the desired 4% ESP. This is the difference between the initial exchangeable sodium and the final desired exchangeable sodium where:

Ca requirement = initial exchangeable Na – final exchangeable Na

Ca requirement = 5.6 – 2.4 = 3.2 meq Ca/100 g needed to displace the 3.2 meq Na/100g soil from the soil CEC

STEP 4

Use Table 2 to determine tons per ac foot soil to replace calculated Ca meq/ 100 grams soil. Gypsum supplies 1.0 meq Ca for every 1.7 tons of material applied (Table 2). If 3.2 meq Ca are needed to reduce the ESP to less than 4%, then approximately 5.5 tons of 100% pure gypsum per ac ft soil is needed to improve the balance of Ca and Na to improve soil structure and infiltration. A single application should not exceed 4 to 6 tons per acre, and must be followed by leaching to remove the Na.

STEP 5

The application rate can be adjusted for a smaller area if only applying as a band along the drip hose. If 5.5 tons per acre needed to cover an acre to a depth of 1 foot, determine the application rate per square ft based on the number of rows in the orchard, the length of each tree row, and the band width.

A 75-acre orchard has 120 rows that are 1280 ft long. A 2-ft band of gypsum will be applied along each row. Calculate the square ft of applied material.

120 rows x 1280 ft row length x 2 ft band of 100% gypsum = 307,200 square ft

Calculate the tons of gypsum amendment needed for the banded area:

There are 43,560 square feet to an acre

307,200 square ft ÷ 43,560 sq ft per acre = 7.05 ac

5.5 tons per ac foot x 7.05 acres = 39 tons 100% gypsum for the 75-acre orchard or about 0.5 tons per acre will be needed to band the material along the dripline of each row.

STEP 6

Begin dormant season leaching to move salts from the rootzone following guidelines in Table 3 on page 9.

TABLE 2

Rates of calcium or acid- based amendments needed to supply 1 meq Ca per acre foot of water or tons of material per acre foot of soil to replace 1 meq Na. Sulfur based amendments require sufficient Ca in the soil to form gypsum, adapted from Carrow and Duncan, 2012.

Rates of Calcium or Acid- Based Amendments		
Amendments	lbs material per ac ft water to supply 1 meq Ca	tons per ac foot soil to supply 1 meq Ca
Gypsum (23%Ca, 19%S)	234	1.7
Sulfuric Acid 100% S	133	1
Sulfur 100% S	44	0.3
Lime sulfur (9% Ca, 24% S)	191	1.4
Nitro sulfur (20% N, 40%S)	109	0.8
Nphuric (10%N 18%S)	242	1.8

IRRIGATION WATER AMENDMENTS

Calcium containing liquid fertilizers and amendments applied in frequent small amounts by drip or micro irrigation may be needed to treat the irrigation water and maintain a good Ca balance in the wetted root zone during the growing season. Determining the type and rate of amendments to add to irrigation water requires knowing the overall salinity (EC) and the composition of Na relative to Ca and Mg, a measure known as the sodium absorption ratio (SAR) expressed as:

$$SAR = Na \div \sqrt{((Ca^{++} + Mg^{++}) \div 2)}$$

The relationship between SAR and the EC level in irrigation water is commonly used as an indicator of Na induced water infiltration problems. In general, when the SAR is greater than five times the overall salinity, moderate to severe reduction in water infiltration rate is likely to occur. The goal of amending irrigation water is to change the proportions of SAR to EC so that no reduction in infiltration rate occurs. To calculate the lbs of Ca supplying material to add to 1-ac ft irrigation water, determine how increasing Ca meq/L will adjust the SAR and EC and improve the infiltration rate of water (Figure 5).

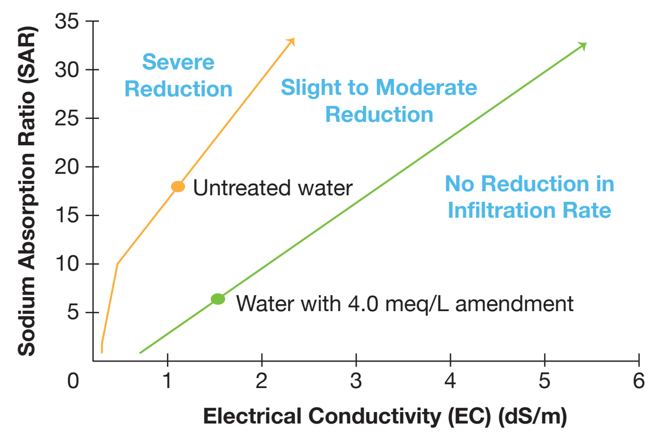


FIGURE 5

Relationship between SAR and the EC level before (orange dot) and after (green dot) 4.0 meq/L amendment added to irrigation water to reduce Na induced water infiltration problems. Adapted from Sanden et al. 2016.

Example to calculate the lbs of Ca supplying material to add to 1-ac ft irrigation water:

STEP 1

Evaluate the relationship of SAR to EC based on a laboratory water quality analysis. The intersection between irrigation water SAR 18.6 (vertical axis) and EC 1.1 dS/m (horizontal axis) marked with an orange circle in Figure 5, shows a "severe reduction" in infiltration rate of applied water:

Ca = 0.4 meq/L

Mg = 0.2 meq/L

Na = 10.2 meq/L

EC = 1.1 dS/m

SAR = 18.6

STEP 2

Calculate a change in EC, SAR and infiltration rate with amendments.

If 4 meq/L Ca are added to the irrigation water with one of the materials listed in Table 3, the EC and SAR can be recalculated using the meq/L of Ca, Mg, and Na in the amended irrigaiton water.

Ca = (4.0 + 0.4 meq/L)

New Ca = 4.4 meq/L

Mg = 0.2 meq/L

Na = 10.2 meq/L

New EC = 4.4 + 0.2 + 10.2 ÷ 10

New EC = 1.5

$SAR = Na \div \sqrt{((Ca^{++} + Mg^{++}) \div 2)}$

$New\ SAR = 10.2 \div \sqrt{((4.4 + 0.2) \div 2)}$

New SAR = 6.7

Amending irrigation water with 4.0 meq/L Ca will decrease the ratio of SAR to EC to the "slight to no reduction in infiltration" category (Figure 5).

STEP 3

Use Table 2 to determine lbs per ac foot water to supply 4 meq/L Ca. Gypsum supplies 1.0 meq/L Ca for every 234 lbs of material applied (Table 2). If 4 meq/L Ca are needed, then:

234 lbs 100% pure gypsum per ac ft x 4.0 meq/L Ca = 936 lbs per ac ft water

COMPOSTS, BIO-STIMULANTS, AND COVER CROP AMENDMENTS

The use of organic materials including composts, mulches and cover crops are another consideration for amending soil. Organic matter enhances microbial activity leading to soil aggregation and improved infiltration and can enhance the effectiveness of other amendments. Composts and mulches can also be sources of salt; therefore, laboratory analysis of these materials is recommended before use. Ongoing research is investigating whether additional surfactants, polymers, bio stimulants and nutrient amendments reduce soil salinity and improve tree growth and yield. Cover crops have been shown to improve water infiltration, protect the soil from surface crusting, and in some instances, significantly reduce soil Na levels.

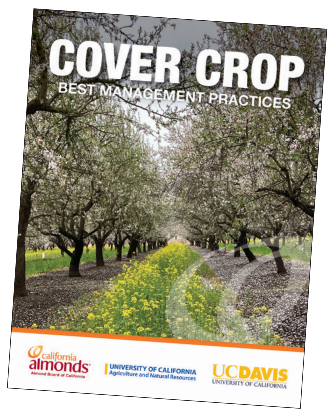


TABLE 3

The depth of water (in/ft) required to reduce soil EC to 1.5 dS/m adapted from the reclamation curves for saline soils using intermitten ponding or sprinkling methods (Pritchard et al. 1985)

LEACHING SALTS FROM THE ROOTZONE

Amendments alone will not reduce soil salinity and must be followed by leaching to be successful. Any excess applied Ca that does not displace and leach Na has the potential to precipitate to form lime and worsen soil infiltration problems. Once the appropriate amendments have been applied to the soil, the calculated amount of water needed will depend on the texture of the soil, the EC level of the rootzone, the final salinity level goal, and the EC of the reclamation water. Table 3 provides general guidelines for the depth of water needed to lower EC below 1.5 dS/m for different average rootzone levels of salinity from 1-6 dS/m. Make dormant salinity amendment applications in the fall prior to rain and leaching. Depending on the soil texture and salt load, 6-10 inches of effective rainfall (penetrating past a 2" depth) or fresh-water winter irrigation is needed for efficient leaching. The first application should fill the soil profile to field capacity. Allow 2-4 days for drainage, then begin leaching applications. Irrigators should make sure to keep irrigation sets to less than 24 hours to avoid the risk of soil saturation and *Phytopthora*. A good strategy is to begin applying water in January (one inch per event) and continue applying one inch every few weeks with the goal of reaching the target 6-10" before mid-February. Soil and irrigation water should be sampled again to determine effectiveness of the leaching and provide a reference point for the salt levels at the beginning and end of the growing season.

Water Depth to Reduce Soil EC					
Soil Average Rootzone dS/m	2	3	4	5	6
Depth of Water (in/ft soil) to Lower EC to 1.5 dS/m	2.4	3.6	5	6	7.2

FREE GROWER RESOURCES

Scan the QR code below and fill out the form to receive your free Almond Board of California resources like these examples shown and more.

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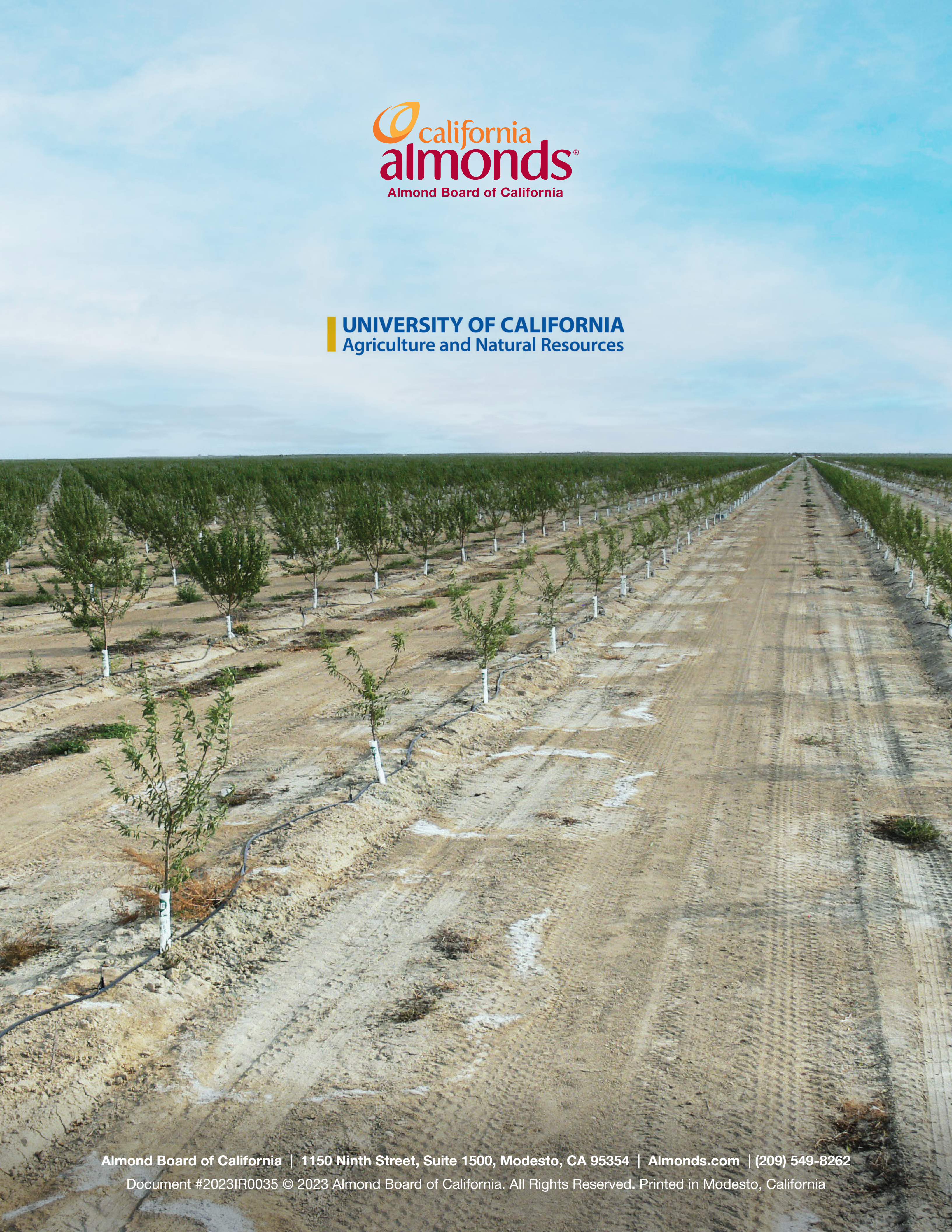

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