

Soil and Water Salinity

Salinity refers to the presence of salts in water and soil. The salts include more than simply sodium or chloride, the two elements of common table salt: magnesium, calcium, bicarbonate, nitrate, and sulfate can also contribute to salinity. The suitability of water for drinking, irrigation, or wildlife depends on the type and concentration of salts dissolved in water. The salinity of water is usually expressed in terms of an easily measured parameter called electrical conductivity (EC) that reflects the total dissolved salt (TDS) concentration of the water or soil-water. Typically, EC is expressed as decisiemens per meter (dS/m), where 1 dS/m represents a TDS concentration of about 640 mg/L salt (see Hanson 2006). This conversion factor depends on the concentration and composition of the salts in solution. Safe drinking water limits for salinity are generally considered to be <1 dS/m. This publication uses this threshold to label saline waters as those with a salinity >1 dS/m. Saline soils are generally characterized as having soil-water salinity >4 dS/m, but this particular definition is often crop dependent, as many crops do not tolerate such high salinity.

DROUGHT TIP

Use of Saline Drain Water for Crop Production

Some irrigated regions of California accumulate saline drain water as a result of the leaching needed to maintain crop production, but they have limited options for disposal of this saline water. Reusing saline drain water for irrigation as a means of disposal and augmentation of water supplies has been of interest for decades, especially when other water supplies become scarce during droughts. Using saline drain water (water with salinity >1 dS/m; see sidebar) for irrigation was described for many semiarid locations around the world in a guidance document published by the United Nations (Rhoades et al. 1992). Similarly, the California Department of Water Resources (DWR) considered drain water reuse for irrigation as part of the San Joaquin Valley Drainage Program (Aleml 1999). Under drought conditions, drainage water may be used to supplement regular irrigation to meet crop water demands or possibly to maintain established tree or vine crops if root zone salinity is carefully managed. This publication considers some of the more recent research related to the use of saline water for irrigation of agricultural crops and describes the management of this water to maintain crop production and acceptable root zone soil salinity.

MARK E. GRISMER, Professor,
Land, Air, and Water Resources,
University of California, Davis;
and KHALED M. BALI, County
Director and Irrigation/Water
Management Advisor, University
of California Cooperative
Extension, Imperial County

Research Overview

The quality of subsurface drainage water depends on the quality of the applied water and the extent of root zone leaching of salts, applied fertilizers, herbicides, and pesticides during the irrigation season. Collected subsurface drain water can be saline and may have elevated boron (B) concentrations. Public concern over possible food crop contamination, as well as grower concern about possible long-term physical and chemical (e.g. salinization) deterioration of the root zone from regular use of drain water for irrigation, has typically limited its use to moderately salt-tolerant forage and fiber crops, though saline water

has been used for irrigation of other crops as well. Establishing an annual salt balance in the crop root zone is critical for maintaining the annual steady-state leaching that minimizes root zone accumulation of soil salinity (Grismer 1990) necessary for long-term sustainable drain water use in any region (Ayars et al. 2006b).

The use of saline drain water as a supplemental source of irrigation water has been studied extensively (Ayars et al. 1993; Rhoades et al. 1980, 1989; Rhoades 1989; Rhoades 1984a). Rhoades et al. (1989) found the use of low to moderately saline water cycled with good-quality water to be an effective method for using saline water as supplemental irrigation without producing negative effects on yield and soil quality. For example, Ayars et al. (1993) used saline (~7 dS/m) water to irrigate cotton and found that yields were maintained and soil salinity could be managed with a preplant irrigation of good-quality water. The high level of boron in the drainage water and the accumulation of boron in the crop root zone found by Ayars et al. were identified as potential problems in long-term use of water containing high levels of boron. Similarly, Ayars et al. (2006a) used saline (3 to 6 dS/m) drain water for irrigation of alfalfa hay between cuttings and found improved hay quality but decreased yields. Using in-situ groundwater may be preferable over drain water since it is more energy efficient for the plants to extract water directly from the source than using pumps to irrigate (Bali et al. 2001).

Subsurface Drain Water Characteristics

The quality of subsurface drain water depends on the quality of the applied irrigation water, root zone salinity, and the extent of soil leaching before collection by the drainage system. For example, in the Imperial Valley of southern California, the salinity of the average shallow groundwater collected by the Valley drainage system is about 6 to 7 dS/m, while the salinity of applied water is about 1.2 dS/m. Similarly, in the San Joaquin Valley, salinity of applied water is roughly 0.5 dS/m, and the salinity of collected drain water is 3 to 6 dS/m.

A key advantage of collected drain water during drought is that it may be available at predictable monthly or annual rates associated with local irrigation scheduling. It may be possible

to obtain drain water at little or no cost to growers beyond that required for pumping and transport because there are very limited, if any, discharge options for saline drain water disposal. Interested growers should inquire with their local water agency about the possibility of obtaining drain water and should get information about the monthly average water quality, particularly the drain water salinity (EC), boron, and major anion/cation concentrations. This latter information is critical for irrigation and root zone salinity management using drain water.

Considerations When Irrigating with Subsurface Drainage Water

Saline drain water can be used for irrigation in areas with or without subsurface drainage systems. However, using saline water for irrigation should be carefully considered in undrained areas affected by shallow groundwater because salt accumulation in the root zone is more difficult to manage. In addition to improved root zone leaching, subsurface drainage systems enable management of shallow water tables, another possible water source to meet crop water demand (see Grismer and Bali 2015).

Applying drain water using an irrigation system enables greater control of timing, depth of irrigation, and blending with good-quality water so that drain water can be used longer during the growing season. This additional control also allows for the careful management of root zone salinity during drought, especially as compared with manipulation of the shallow groundwater table.

Several irrigation management strategies using saline drain water are based on three general strategies that depend on the crops grown and the availability and salinity of the drain water and regular irrigation water (Grattan et al. 2012). These general strategies include

- blending the saline water with regular irrigation water to reduce the applied salinity
- irrigating with the saline water during the less salt-sensitive crop growth stages between germination and initial development, and also probably before harvest
- alternating fresh and saline water irrigation, such as by establishing successively more salt-tolerant crops with good-quality irrigation

water, then applying saline water until harvest, followed by irrigating a new crop with good-quality water in the subsequent season.

Any irrigation scheduling method can be used to determine the depth and timing of saline water applications. An appropriate leaching fraction (roughly 10 to 30% additional water) can be added to the seasonal applied water based on the average applied water quality (e.g., blended or alternating drain water and regular water), the irrigation system used, and the crop salt tolerance. The timing and amount of saline water substitution varies with the salinity of the regular water and saline drain water, cropping pattern, climate, soil properties, irrigation management, and irrigation system.

Growers may also need to consider the sodium adsorption ratio (SAR) of the applied water and soil-water with respect to possible infiltration problems during irrigation. The SAR indicates how much sodium is in the water relative to calcium plus magnesium. If the SAR of the soil-water or applied water is greater than about 3 dS/m, infiltration rates in loam and clay loam soils may be reduced, resulting in longer irrigation application times (for guidelines, see Alemi 1999, p. 18). In these conditions, gypsum applications have been found to improve infiltration rates. Root zone salt buildup that occurs from irrigating with saline water can be alleviated in the subsequent cropping period with a preplant irrigation using low-salinity irrigation water or by facilitating rainfall leaching of the root zone through tillage practices. In either case, root zone salinity monitoring is required to guide selection of irrigation water with acceptable salinity so that the salinity of the root zone remains within a few multiples of the crop salt tolerance threshold.

Figure 1 summarizes the general relationships between applied water salinity, leaching fraction, and soil salinity that can be used with the salinity tolerance table (see table 1). The leaching fraction (LF) is the portion of infiltrated water that drains below the root zone. Determining whether rainfall or irrigation leaching is controlling root zone salinity (Grismer 1990) is critical for developing long-term sustainable saline water use strategies

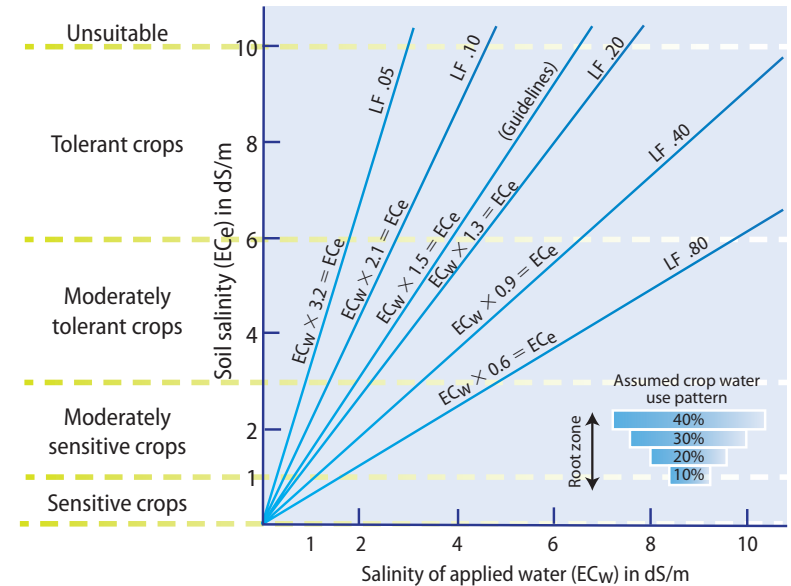


Figure 1. Effect of applied water salinity (EC_w) on root zone soil salinity (EC_e) at various leaching fractions (LF). Source: Ayers and Westcott 1985, chap. 2.4.

in any region and should be considered as part of the irrigation management strategy for fields where saline drain water is applied.

Crop Salinity Tolerance

While most field crops such as alfalfa hay and cotton are moderately salt tolerant, vegetable crops are typically more sensitive to salinity, and reuse of saline water in vegetable crop production may not be feasible if the salinity of the applied water (drain or blended) exceeds 3 dS/m. Salts present in the soil-water can reduce crop yield and product quality. Salinity can effect crop growth through specific ion toxicities and osmotic effects. Specific ion toxicity occurs when a particular ion concentration is sufficient to cause toxicity. Boron, chloride, and sodium are few of the ions that impede plant growth

and development. Specific ion toxicity causes leaf burn on the tips and margins of crop leaves. Osmotic stress refers to the reduction in plant-available water potential in the soil because plant-water may move across the root cell membrane from the plant into the soil as a result of the salinity gradient. At normal salinity levels, water moves from the soil-water system to plant roots because of the higher concentration of constituents in the root cells. This adjustment inside cells requires metabolic energy, and the adjustment in some crops is more efficient than others, giving them higher tolerance to salinity. Consequently, osmotic effects may reduce crop yield to varying degrees and affect crop quality as well. The effect of overall soil salinity on vegetable crop yield can be described by the Maas-Hoffman yield loss equation

$$Y = 100 - B (EC_e - A)$$

illustrated in figure 2. In this equation, Y is the relative yield (%), A is threshold value (dS/m, the maximum root salinity at which no reduction in yield is observed), B is percentage of reduction in yield due to an increase of 1 unit of salinity above the threshold value, and EC_e is the average root zone salinity. Soil salinity levels at or below the threshold value A do not affect crop yield or quality.

Selected Maas-Hoffman A and B values for various vegetable crops grown in California are summarized in table 1 (for additional crops see Grieve et al. 2012). The key practical aspect for maintaining crop production using saline drain water is to ensure that root zone salinity during germination and early growth stages are below the threshold values listed and within one or two multiples of the threshold values during the irrigation season. This latter observation suggests that during drought periods, saline drainage water may be used after the crop is well established. Growers may select progressively more salt-tolerant crops (greater threshold salinity A values) that have smaller yield losses per unit of increase in applied water salinity (B values) as fresh water supplies diminish and there is a greater reliance on the use of saline drain water for irrigation. Additional irrigations may be required so as to not to impose salt and water stress on the crop at the same time. For example, deficit irrigation strategies found effective with good-

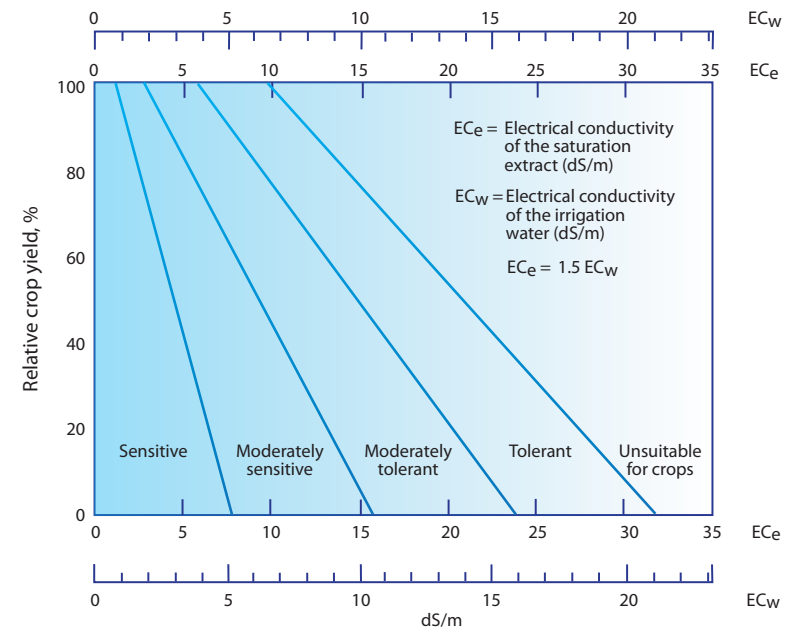


Figure 2. Illustration of the Maas-Hoffman yield loss equation and relative salt tolerance ratings of agricultural crops. *Source:* Ayers and Westcott 1985, chap. 2.4.

quality water can be devastating when using saline drainage water, especially early in the growing season.

Conclusions and Recommendations

Saline drain water available from subsurface drainage systems can be a water source for irrigation and agricultural production in California. In fields with subsurface drainage systems in which growers can manipulate shallow groundwater levels, it would be more cost-effective to simply manage the water table elevation and let the crop make direct use of the shallow groundwater. Nonetheless, long-term studies using saline water for irrigation of various crops have indicated that it can be successfully used while maintaining crop yields if growers carefully manage soil root zone moisture and salinity through application of a leaching fraction addition to the saline water irrigations, followed by irrigation with low-salinity water at least

Table 1. Salt tolerance of common vegetable, grain, grass, and forage crops in California.

Crop	Threshold salinity (A) (dS/m)	Slope (B) (% loss per dS/m)	Salt tolerance level
alfalfa	2.0	7.3	moderately sensitive
asparagus	4.1	2.0	tolerant
barley	8.0	5.0	tolerant
beans	1.0	19.0	sensitive
bermudagrass	6.9	6.4	tolerant
broccoli	2.8	9.2	moderately sensitive
carrot	1.0	14.0	sensitive
celery	1.8	6.2	moderately sensitive
corn	1.8	7.4	moderately sensitive
cucumber	2.5	13.0	moderately sensitive
grapes	1.5	9.6	moderately sensitive
lettuce	1.3	13.0	sensitive
oats	see barley		tolerant
onions	1.2	16.0	sensitive
peppers	1.5	14.0	moderately sensitive
potatoes	1.7	12.0	moderately sensitive
radishes	1.2	13.0	moderately sensitive
safflower	—	—	moderately tolerant
spinach	2.0	7.6	moderately sensitive
sudangrass	2.8	4.3	moderately tolerant
sugar beets	7.0	5.9	tolerant
tomatoes	2.5	9.9	moderately sensitive
wheat	6.0	7.1	moderately tolerant

between growing seasons. Growers interested in obtaining and using drain water for crop production should

- contact local water agencies to obtain information on drain water availability, average monthly water quality, and anticipated costs for use, pumping, and transport to their fields

- determine the average soil root zone salinity (depth is crop dependent; we suggest soil sampling at depths of 6, 12, 24, and 36 inches) at the end of the summer irrigation season (prior to rainy weather) and after the rainy season to assess root zone Na, Cl, SAR and salinity levels
- consider blending or cycling application of saline drain water with good-quality groundwater or surface water supplies to manage the salinity of application water and the root zone
- monitor soil Na, Cl, B, SAR, and salinity levels at least annually (at the end of the summer irrigation season), and preferably twice per year, to ensure that soil root zone conditions are acceptable

References

- Alemi, M. 1999. Drainage reuse, final report, task 1. San Joaquin Valley Drainage Program. Sacramento: DWR. DWR website, www.water.ca.gov/pubs/groundwater/drainage_reuse_final_report_-_san_joaquin_valley_drainage_implementation_program/03-reuse.pdf.
- Ayars, J. E., R. B. Hutmacher, R. A. Schoneman, S. S. Vail, and T. Pflaum. 1993. Long-term use of saline water for irrigation. *Irrigation Science* 14:27–34.
- Ayars, J. E., R. W. Soppe, and P. Shouse. 2006a. Alfalfa production using saline drainage water. USCID 4th International Conference Proceedings. 287–301.
- Ayars, J. E., E. W. Christen, R. W. O. Soppe, and W. S. Meyer. 2006b. Resource potential of shallow groundwater for crop water use: A review. *Irrigation Science* 24:147–160.
- Ayers, R. S., and D. W. Westcott. 1985. Water quality for agriculture. Rome, Italy: Food and Agriculture Organization of the United Nations. FAO website, www.fao.org/DOCRp/003/T0234e/T0234E03.htm.
- Bali, K. M., M. E. Grismer, and R. L. Snyder. 2001. Alfalfa water use pinpointed in saline, shallow water tables of Imperial Valley. *California Agriculture* 55(4): 38–43.

- Grattan, S. R., J. D. Oster, S. E. Benes, and S. R. Kaffka. 2012. Use of saline drainage waters for irrigation. In W.W. Wallender and K.K. Tanji, eds., *Agricultural salinity assessment and management*. 2nd ed. Reston, VA: American Society of Civil Engineers. 687–719.
- Grieve, C. M., S. R. Grattan, and E. V. Maas. 2012. Plant salt tolerance. In W.W. Wallender and K. K. Tanji, eds., *Agricultural salinity assessment and management*. 2nd ed. Reston, VA: American Society of Civil Engineers. 405–459.
- Grismer, M. E. 1990. Leaching fraction, soil salinity, and drainage efficiency. *California Agriculture* 44(6): 24–27.
- Grismer, M. E. 2015. Drought tip: Use of shallow groundwater for crop production. Oakland: University of California Agriculture and Natural Resources Publication 8521. UC ANR catalog website, anrcatalog.ucanr.edu/Details.aspx?itemNo=8521.
- Hanson, B. 2006. *Agricultural salinity and drainage*. Oakland: University of California Agriculture and Natural Resources Publication 3375.
- Rhoades, J. D. 1984a. Use of saline water for irrigation. *California Agriculture* 38(10): 42–43.
- . 1984b. New strategy for using saline waters for irrigation. In J. A. Replogle and K. G. Renard, ed., *Proceedings ASCE Irrigation and Drainage Specialty Conference: Water today and tomorrow*. New York: American Society of Civil Engineers. 231–236.
- Rhoades, J. D., S. L. Rawlins, and C. J. Phene. 1980. Irrigation of cotton with saline drainage water. American Society of Civil Engineers, Convention and Exposition, Portland, OR, April. Preprint 80–119.
- Rhoades, J. D., F. T. Bingham, J. Letey, G. I. Hoffman, A. R. Dedrick, P. J. Pinter, and J. A. Replogl. 1989. Use of saline drainage water for irrigation: Imperial Valley study. *Agricultural Water Management* 16:25–36.

Rhoades, J. D., A. Kandiah, and A. M. Marshali. 1992. *The use of saline waters for crop production*. Rome, Italy: UN FAO Irrigation & Drainage paper 48. FAO website, www.fao.org/docrep/t0667e/t0667e00.HTM.



This publication was written and produced by the University of California Agriculture and Natural Resources under agreement with the California Department of Water Resources.

To order or obtain ANR publications and other products, visit the ANR Communication Services online catalog at anrcatalog.ucanr.edu/ or phone 1-800-994-8849. You can also place orders by mail or FAX, or request a printed catalog of our products from

University of California
Agriculture and Natural Resources
Communication Services
1301 S. 46th Street, Building 478 - MC 3580
Richmond, CA 94804-4600

Telephone 1-800-994-8849, 510-665-2195, FAX 510-665-3427
E-mail: anrcatalog@ucanr.edu

©2015 The Regents of the University of California. This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view a copy of this license, visit creativecommons.org/licenses/by-nc-nd/4.0/ or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.

Publication 8554

ISBN-13: 978-1-60107-952-7

The University of California, Division of Agriculture and Natural Resources (UC ANR) prohibits discrimination against or harassment of any person on the basis of race, color, national origin, religion, sex, gender, gender expression, gender identity, pregnancy (which includes pregnancy, childbirth, and medical conditions related to pregnancy or childbirth), physical or mental disability, medical condition (cancer-related or genetic characteristics), genetic information (including family medical history), ancestry, marital status, age, sexual orientation, citizenship, status as a protected veteran or service in the uniformed services (as defined by the Uniformed Services Employment and Reemployment Rights Act of 1994 [USERRA]), as well as state military and naval service. The University also prohibits sexual harassment and sexual violence.

An electronic copy of this publication can be found at the ANR Communication Services catalog website, anrcatalog.ucanr.edu/.

This publication has been anonymously peer reviewed for technical accuracy by University of California scientists and other qualified professionals. This review process was managed by ANR Associate Editor for Land, Air, and Water Sciences Allan Fulton.

web-10/15-SB/CR