University *of* California
Agriculture and Natural Resources

ANR Publication 8550 | November 2015
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Figure 1. Drainage can be improved using cover crops (A), compost amendments (B), and deep tillage (C) to increase the macropore structure of soils *Photos: M. Cahn, A and B; J. Mitchell, C.*

DROUGHT TIP

Managing Salts by Leaching

Leaching for Salt Management

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Irrigating crops can often cause salts to build up in the soil profile. Irrigation water applied to crops may contain a significant amount of dissolved salts. For example, applying 1 acre-foot of water with a total dissolved salt concentration of about 735 ppm, or an electrical conductivity (EC) of 1.15 dS/m, would potentially add 1 ton of salt to 1 acre of cropped land. Salts accumulate in the soil because crop roots take up water during transpiration but exclude most salts. Salt also accumulates near or at the soil surface because water evaporating from the soil leaves behind dissolved salt. These accumulated salts can damage crops if they are not leached below the root zone.

Leaching is the process of percolating water through the soil profile to move salts below the root zone, the region of the soil where crop roots normally grow. During the growing season, leaching can be accomplished by applying extra water so that the amount exceeds the evapotranspiration requirement of the crop. Leaching can also be done by irrigating a field before planting a crop or by irrigating before permanent crops leaf out in the spring. Salts can also be leached after harvest or by winter rainfall if sufficient.

Leaching is beneficial for removing salts only if the soil has adequate drainage. Compacted layers that impede water movement can prevent leached salts from moving below the root zone. Practices such as deep tillage, incorporation of soil amendments such as compost or gypsum, and rotating with deep-rooted cover crops such as cereals can increase the volume of macropores in the soil and improve drainage (fig. 1). Subsurface drainage systems are also commonly used to improve drainage from fields with shallow or perched water tables.

Though leaching is beneficial for removing salts from the crop root zone, leached salts can contribute to a number of environmental problems. Nutrients including nitrate and in some cases orthophosphate as well as some pesticides can leach into subsurface drainage systems and contribute to degraded water quality in lakes and rivers. Concentrated salts from subsurface drainage systems also impact the quality of surface water bodies. Leached nitrate can contaminate groundwater to the point that it is unsafe for human consumption.

Nutrient losses can be reduced by not leaching immediately following fertilizer applications or when the soil has a high concentration of nitrate. Also, using best management practices for irrigation and nutrient management can minimize losses of nitrate and phosphorus. In addition, using an appropriate amount of leaching to achieve desired soil salinity levels minimizes drainage and nutrient losses.

Under drought conditions, when the supply of water is limited, using an appropriate leaching strategy can optimize water use and yield.

Leaching Requirement and Leaching Fraction

The leaching requirement (LR) is defined as the amount of water that is needed to maintain crop productivity. It depends on the salinity of irrigation water, soil salinity, salt crop tolerance, irrigation management, and other factors. The leaching fraction (LF) is the amount of leaching that has occurred in a field; it is defined as the fraction of the applied water (irrigation plus rainfall minus surface runoff) that drains below the root zone:

$$LF = D \div AW$$

where D is the depth of water draining below the root zone and AW is the depth of water applied (irrigation plus rainfall) that infiltrates the soil. A high leaching fraction (> 0.5) reduces salt accumulation in the root zone more than does a low leaching fraction (< 0.1).

The leaching requirement and leaching fraction are frequently expressed as a percentage by multiplying the result of the above equation by 100.

Estimating Applied Water for a Desired Leaching Requirement

To determine how much water to apply to meet crop ET demands and the leaching requirement, use the following equation:

$$AW = ETc \div [1 - (LR \div 100)]$$

where AW is applied water depth in inches, ETc is crop evapotranspiration in inches, and LR is the leaching requirement (%). For example, if a leaching requirement of 30% is desired and crop ET is estimated to be 0.7 inches, 1 inch of water must be applied:

$$AW = 0.7 \text{ in} \div [1 - (30 \div 100)]$$
$$AW = 1 \text{ in}$$

Note that 43% more water than ETc (143% of ETc) was applied to attain a 30% leaching fraction. To attain a 50% leaching fraction, twice as much water as ETc (0.7 inches ÷ 0.5 = 1.4 inches) must be applied. As an alternative to the above equation, use Table 1 to determine the amount of applied water expressed as a percentage of crop ET to attain a desired leaching fraction.

Table 1. Applied water, expressed as percentage of crop ET, need to attain a desired leaching fraction

Leaching fraction (%)	Applied water as a percentage of crop ET
5	105
10	111
15	118
20	125
25	133
30	143
35	154
40	167
50	200
60	250

Determining the Leaching Requirement for a Crop

Using an appropriate leaching requirement when irrigating can prevent salts from building up in the root zone of crops and can minimize loading of nutrients, such as nitrate, and other salts to ground and surface water. A small LR may be used when a crop is tolerant to salts or when the irrigation water has a low salinity content, and a large LR may be needed for a salt-sensitive crop or when the irrigation water is high in salts. To determine the LR, use the following steps.

Step 1. Determine the soil salinity (ECe) threshold that causes yield loss for a crop type (see Ayers and Westcott 1985). These values are published more extensively in ANR Publication 8554, *Use of Saline Drain Water for Crop Production* (Grismer and Bali, in process). Soil salinity thresholds for some common crops are summarized in table 2.

Step 2. Determine the average salinity of the water used to irrigate the crop. Most water suitability tests report salinity concentration either in units of electrical conductivity (dS/m, µS/cm, or mmhos/cm) or in units corresponding to concentration (ppm or mg/L). Salinity values in units of dS/m are needed for calculating the LR in the next step. Conversions to dS/m are:

1 dS/m = 1 mmhos/cm
1 dS/m = 1000 µS/cm
1 dS/m = 640 ppm = 640 mg/L

Step 3. The final step is to use the equation below to estimate the leaching requirement:

$$LR = (ECw \times 100) \div [(ECe \times 5) - ECw]$$

where ECw is the salinity of the irrigation water and ECe is the soil salinity threshold in the root zone above which crop yield is reduced (from table 2). Alternatively, use table 3 to estimate a leaching requirement by finding the intersection of the ECw value of the irrigation water and the ECe threshold of the crop.

Table 2. Soil salinity thresholds determined from saturated soil paste extracts (ECe) that cause yield loss in agronomic and horticultural crops

Crop	ECe (dS/m)	Salt tolerance
Agronomic crops		
alfalfa	2.0	moderately sensitive
barley	8.0	tolerant
corn	1.7	sensitive
cotton	7.7	tolerant
dry bean	1.0	sensitive
rice	3.0	moderately sensitive
sorghum	6.8	tolerant
wheat	6.0	tolerant
Vegetable crops		
broccoli	2.8	moderately sensitive
cabbage	1.8	moderately sensitive
carrot	1.0	sensitive
celery	1.8	moderately sensitive
garlic	3.0	sensitive
lettuce	1.3	moderately sensitive
onion	1.2	sensitive
pepper	1.5	moderately sensitive
potato	1.7	moderately sensitive
spinach	2.0	moderately sensitive
squash	4.7	moderately tolerant
tomato	2.5	moderately sensitive
Perennial crops		
almond	1.5	sensitive
apricot	1.6	sensitive
blackberry	1.5	sensitive
grape	1.5	tolerant
orange	1.7	tolerant
peach	1.7	tolerant
plum (prune)	1.5	moderately sensitive
strawberry	1.0	sensitive

Source: Ayers and Westcott 1985.

Table 3. Leaching requirement (LR), expressed as percentage, to achieve a desired soil salinity concentration (EC_e) in the crop root zone using irrigation water of varying salinity concentrations (EC_w). The intersection between the EC_w and EC_e values correspond to the appropriate LR.

Soil salinity (ECe), dS/m	Salinity of irrigation water (ECw), dS/m												
	0.2	0.5	0.7	1	1.3	1.5	2	2.5	3	4	5	6	7
0.5	9	25	39	67	108	—	—	—	—	—	—	—	—
1	4	11	16	25	35	43	67	100	—	—	—	—	—
1.5	3	7	10	15	21	25	36	50	67	114	—	—	—
2	2	5	8	11	15	18	25	33	43	67	100	—	—
2.5	2	4	6	9	12	14	19	25	32	47	67	92	—
3	1	3	5	7	9	11	15	20	25	36	50	67	88
3.5	1	3	4	6	8	9	13	17	21	30	40	52	67
4	1	3	4	5	7	8	11	14	18	25	33	43	54
4.5	1	2	3	5	6	7	10	13	15	22	29	36	45
5	1	2	3	4	5	6	9	11	14	19	25	32	39
5.5	1	2	3	4	5	6	8	10	12	17	22	28	34
6	1	2	2	3	5	5	7	9	11	15	20	25	30
6.5	1	2	2	3	4	5	7	8	10	14	18	23	27
7	1	1	2	3	4	4	6	8	9	13	17	21	25

Example: Tomato has a soil salinity threshold of 2.5 dS/m (table 2). If the salinity of the irrigation water is 1.5 dS/m, what is the appropriate leaching requirement (percent)? The answer can be calculated directly using the above equation or by using table 3:

$$LR = (1.5\ \text{dS/m} \times 100) \div [(5 \times 2.5\ \text{dS/m}) - 1.5\ \text{dS/m}]$$

$$LR = 14\%$$

The above estimate of leaching requirement assumes that water extracted by the crop to meet ET demand is proportional to the root distribution in the soil profile and follows a 40-30-20-10 extraction pattern. If the root zone of the crop were divided into 4 equal layers of depth, 40% of the roots would be distributed in the upper layer of the root zone, 30% of the roots would be distributed in the second layer, 20% of the roots would be distributed in the third layer, and 10% of the roots would be distributed in the deepest layer of the root zone. Although the depth of the root zone varies among crops, this equation provides a good approximation of LR because the distribution pattern of roots and water extraction in the soil profile is relatively consistent among crop types.

If the water extraction of a crop deviates significantly from this pattern, a different leaching requirement maybe needed. For example, a higher leaching requirement may be needed if a higher portion of the water extraction is near the soil surface. For irrigation water with an ECw equal to 1 dS/m, a water extraction pattern of 50-30-15-5 would result in an ECe in the soil profile averaging 1.8 dS/m for a 15% leaching fraction. For the same irrigation water salinity and leaching fraction, a water extraction pattern of 40-30-20-10 would result in an ECe in the soil profile averaging 1.6 dS/m. Under the shallower rooting pattern, an 18% leaching fraction would be needed to achieve a similar average soil salinity as a 40-30-20-10 extraction pattern. The higher average ECe for the shallow rooting pattern is caused by more salt accumulation near the soil surface. Hence, water draining from the uppermost soil layer would have a higher salinity than for a crop with proportionally more deep roots.

Leaching requirements under microirrigation (drip and microsprinklers) may also differ from conventional methods such as overhead sprinklers and flood irrigation. Crops are usually irrigated more frequently under drip and microsprinklers than under conventional methods, so a consistently higher soil moisture content may minimize the detrimental effects of salt accumulation on crop growth. Also, because the roots of crops grown under drip and microsprinklers tend to concentrate in the zone where water is applied, leaching of salts from the root zone may be more effective than using conventional irrigation methods. For example, in vegetables grown on raised beds, much of the leaching under sprinklers is in the furrows, where the root density and salt accumulation is low. Note that because soil moisture moves laterally under drip, salts may also move laterally and accumulate at the edges of wetted zones.

Since it is difficult to know the exact water extraction pattern of a crop and where salts are accumulating in the soil profile, especially under drip irrigation, periodically assessing whether leaching is adequate by analyzing the soil salinity is recommended.

As indicated in table 3, small leaching fractions are needed when using low-salinity irrigation water (ECw < 1 dS/m) to irrigate crops with salt tolerance thresholds greater than 1.5 dS/m. Much of the surface water used for irrigation in the Sacramento and San Joaquin Valleys has salinity levels less than 0.5 dS/m, and most groundwater frequently used for agricultural irrigation has a salinity of less than 1 dS/m. Salinity of drainage water and recycled water is often more than 1 dS/m. Table 4 lists leaching requirements of selected crops grown in the San Joaquin Valley using water with an average EC of 0.5 dS/m.

Table 4. Estimated leaching requirement for selected San Joaquin Valley crops irrigated with water of an EC of 0.5 dS/m

Crop	Leaching requirement (%)
almond	7
barley	1
broccoli	4
corn	6
cotton	1
dry beans	11
lettuce	8

Factoring Irrigation System Uniformity into the Leaching Requirement

Because no irrigation system applies water perfectly uniformly, extra water is needed to assure that the driest area of a field will receive sufficient water to meet ETc requirements, and that sufficient water drains below the root zone to minimize the buildup of salts. The distribution uniformity (DU) of an irrigation system can be used to estimate the applied water needed to meet crop ET, leaching requirements, and overcome low DU.

$$AW = (ETC \times 100 \div DU) \div [1 - (LR \div 100)]$$

where AW is applied water in inches, ETc is crop evapotranspiration in inches, and LR is percent leaching requirement.

The DU of a perfectly uniform irrigation system is 100%. An irrigation system with a poor DU would be less than 70%, meaning that the average application depth measured in locations representing the driest 25% of an area of a field equals 70% of the average application depth of water applied to the entire field. The area representing the driest 25% of a field is referred to as the "lowest quarter." Table 5 lists the applied water volumes, expressed as a percentage of ETc, that would be necessary to achieve a 5% leaching fraction in the driest area of a field under irrigation systems of different uniformities. An irrigation systems with a high DU theoretically requires less water to satisfy the crop water needs and leach salts.

Table 5. Applied water volume, expressed as a percentage of crop ET, needed to achieve a 5% leaching fraction under irrigation systems with different distribution uniformities (DU)

Irrigation method	DU	Applied water % of crop ET
solid set sprinklers	75	140
linear move sprinklers	80	124
drip	85	111

The effects of an overhead sprinkler system with a low DU on leaching of salts can often be overcome if leaching is split over several irrigations. By moving sprinkler lines over by 10 to 20 feet between irrigations, areas that received less water in the previous irrigation may be compensated with higher volumes during the next irrigation. Also, if wind was a factor in creating dry areas of a field, different wind conditions during subsequent irrigations may compensate dry areas with extra water.

Assessing whether Leaching Is Adequate

An efficient method to assess whether leaching is effective is to measure soil salinity in the root zone of a crop.

Step 1. Sample soil from three to four equal-depth intervals in the root zone. Each depth should be a composite of soil sampled from 8 or more locations within a field.

Step 2. Analyze a saturated pasted extract of the soil sample from each layer for electrical conductivity (ECe).

Step 3. Compare salinity values among different depths. Salt concentration should increase with depth if leaching is effective (fig. 2). If salinity is higher at the surface than deeper in the soil profile (fig. 3), leaching is not sufficient for reducing salts.

Step 4. Finally, assess the effectiveness of a leaching strategy by comparing the average EC of the root zone with the EC of the applied water using the leaching requirement equation presented above:

$$\mathrm{LR} = (\mathrm{ECw} \times 100) \div [(\mathrm{ECe} \times 5) - \mathrm{ECw}]$$

Example: The ECe measured in the root zone of a tomato crop is 2, 2.5, 4, and 6 dS/m for depths at 1, 2, 3, and 4 feet. The EC of the irrigation water is 1.5 dS/m. Find the average ECe of the root zone:

$$(2\ \mathrm{dS/m} + 2.5\ \mathrm{dS/m} + 4\ \mathrm{dS/m} + 6.5\ \mathrm{dS/m}) \div 4 = 3.75\ \mathrm{dS/m}.$$

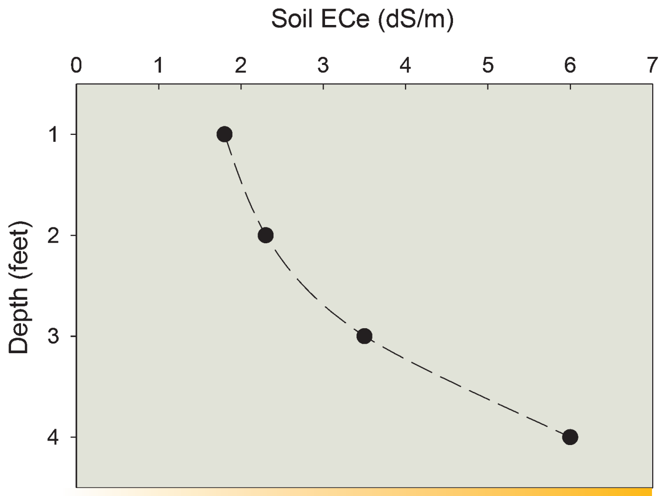

Figure 2. Soil salinity distribution in the root zone of a crop with adequate leaching.

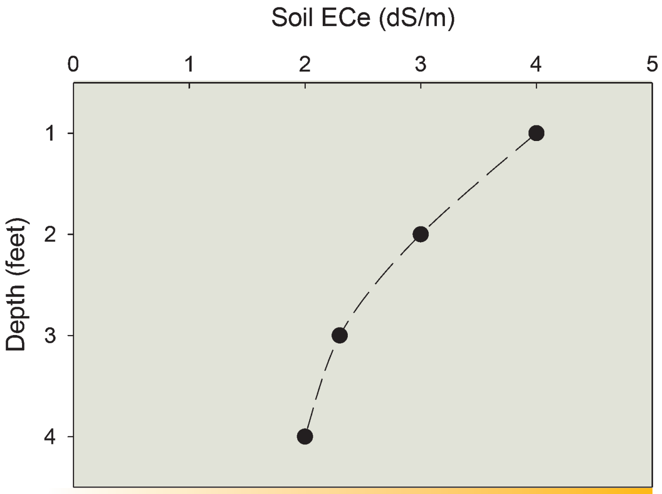

Figure 3. Soil salinity distribution in the root zone of a crop with inadequate leaching. Compare the average soil salinity in the root zone with the EC threshold for the yield loss of the crop. If the soil salinity is significantly higher than the yield threshold, more leaching may be needed.

The threshold for yield loss in tomato is 2.5 dS/m. Since the average root zone EC is higher than the EC threshold for tomato, the leaching fraction used was probably not sufficient to prevent some yield loss. Calculate the actual leaching fraction (LF) used:

$$LF = (EC_w \times 100) \div [(EC_e \times 5) - EC_w]$$
$$LF = (1.5 \text{ dS/m} \times 100) \div [(3.75 \text{ dS/m} \times 5) - 1.5 \text{ dS/m}]$$
$$LF = 8.7\%$$

In the above example, a 9% leaching fraction was insufficient to reduce the average salinity in the root zone to 2.5 dS/m. As estimated in the earlier example, a 14% leaching requirement would be more likely to decrease the soil salinity in the root zone to a level that would minimize yield loss.

Leaching under Drought Conditions

- Under drought conditions, water may be in short supply and it may not be possible to optimize leaching for salinity management.
- Some growers will need to deficit irrigate, which is applying less water than potential evapotranspiration, in order to keep crops alive. The combination of less than normal winter rainfall and deficit irrigation may contribute to higher than normal salinity levels in the root zone of a crop. Growers should consider using every strategy possible to efficiently leach salts when the supply of water is limited.
- Monitoring soil and water salinity can be useful to determine whether leaching is effective. By evaluating soil salinity several times during the season, management changes can be made before crops are harmed. Targeting postseason leaching to areas that have the highest salinity may reduce the leaching requirement needed to optimize crop growth during the production season.
- Leaching requirements may be less under deficit irrigation because the actual ETc will be less than under normal irrigation conditions, and therefore a greater portion of the applied water will percolate below the root zone.
- Irrigating with highly efficient methods such as drip or very uniform sprinklers may help leach salts using less water. With drip, irrigating frequently with small applications of water can avoid excessive depletions of soil moisture and help crops avoid salinity stress.
- Avoid applying high rates of fertilizers or salt containing amendments, such as manures, which may increase the salinity in the root zone of young crops.
- Planting crops that are more salt tolerant may also be an effective option depending on economic considerations.
- Using alternative sources of water, such as treated wastewater, recycled water, or groundwater, may be useful for salt control but may require higher leaching fractions than are needed for higher-quality surface water.

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This publication was written and produced by the University of California Agriculture and Natural Resources under agreement with the California Department of Water Resources (DWR). It is an update of Drought Tip 92-16, which was part of a publication series developed as a cooperative effort by the California DWR; University of California; USDA Drought Response Office and Soil Conservation Service; and the U.S. Department of the Interior Bureau of Reclamation, Mid-Pacific Region.

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Publication 8550
ISBN-13: 978-1-60107-948-0

An electronic copy of this publication can be found at the ANR Communication Services catalog website, http://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 Anthony O'Geen.

web-11/15-SB/CR