IRRIGATION WATER QUALITY IN TREE NURSERIES IN THE INLAND WEST

T.D. Landis
USDA Forest *Service*
Western Nursery Specialist
Lakewood, Colorado

INTRODUCTION

Irrigation water quality is the most critical factor in tree nursery management. Even soil properties are secondary to water quality because poor irrigation water can ruin nursery soil.

The definition of water quality is dependent on use, but for agricultural purposes the concentration and composition of dissolved salts determine its value for irrigation (USDA Salinity Lab 1969). In semiarid climates, where evaporation exceeds precipitation, the soluble salt levels of irrigation water often reach damaging levels. Most of the Inland West is classified as semiarid, especially at lower elevations where most tree nurseries are located.

All plants are susceptible to salt injury under certain conditions; but tree seedlings, and conifers in particular, are very sensitive to soluble salts. Many bare-root tree nurseries in the Inland West have experienced growth problems that can be attributed to soil salinity. Salinity problems can develop in containerized seedling nurseries when irrigation and fertilization are improperly applied.

The objective of this study was to chemically analyze irrigation water from a variety of tree nurseries in the Inland West and to discuss techniques to remedy water quality problems.

SURVEY AND CHEMICAL ANALYSIS

Water samples were collected from 11 forest nurseries in eight western states; two nurseries supplied samples from two different sources (Table 1). The samples were sent in clean plastic bottles to Denver where they were stored under refrigeration (36-38^{o}F) to minimize chemical changes during storage.

Once all 15 samples had been received, they were taken to Agricultural Consultants Laboratory in Brighton, Colorado, for testing. A batch analysis was performed, which reduced the chances for variation due to analytical technique. The complete chemical analysis consisted of total salts as measured by electrical conductivity, pH, and specific ion concentrations of sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), carbonate (CO_3^{--}), bicarbonate (HCO_3^-), sulfate (SO_4^{--}), chloride (Cl^-), nitrate ($NO3^-$), and boron (BO_2) all measured in milliequivalents per litre (California Fertilizer Association 1975).

Two indices of water quality were computed from ion concentrations upon completion of the chemical analyses: adjusted sodium adsorption ratio and residual sodium carbonate (California Fertilizer Association 1975).

Table 1. Salinity hazard

Recommended levels of electrical conductivity (mcmhos/cm)[1]:

Low	<250
Medium	250-750
High	750-2250
Very high	>2250

Nursery	Location	Electrical conductivity (mcmhos/cm)	Rating
Nevada State	Washoe Valley, NV	328	Medium
Nevada State	Tule Springs, NV	368	Medium
Utah State	Draper, UT	265	Medium
Mt. Sopris	Carbondale, CO	397	Medium
Colorado State	Ft. Collins, CO		
	1. College Lake	281	Medium
	2. Greenhouse	58	Low
Albuquerque	Albuquerque, NM		
	1. Reservoir #2	204	Low
	2. Well #2	261	Medium
Mountain Valley	Lincoln, NM	1005	High
Towner	Towner, ND	745	Medium
Lincoln-Oakes	Oakes, ND	675	Medium
Lincoln-Oakes	Bismarck, ND	1460	High
Big Sioux	Watertown, SD	577	Medium
Bessey	Halsey, NE	115	Low
Oklahoma State	Norman, OK	861	High

[1] Page 80 in USDA Salinity Lab. (1969).

WATER QUALITY TEST RESULTS

Soluble salts can injure plants in four ways: 1) reduce moisture availability, 2) decrease soil permeability, 3) cause direct toxicity, and 4) alter nutrient availability (Fuller and Halderman 1975).

1. Salinity Effects on Water Availability

The total concentration of dissolved salts in irrigation water is generally expressed as electrical conductivity, which is measured in units of conductance (micromhos/cm) at a standard temperature (25°C). Dissolved salts decrease the free energy of water molecules and reduce water availability to plants. This osmotic inhibition is a function of total salts irrespective of the specific ions.

The salinity hazard has been divided into four ratings based on observed effects on plant growth (Table 1). Most of the nurseries tested in the medium salinity category, with three each in the high and low classes. None of the irrigation water samples exceeded 2250 mcmhos/cm (the very high category), which has been given as the upper limit for successful agriculture (USDA Salinity Lab 1969).

2. Decrease Soil Permeability

Water quality can also reduce plant growth indirectly through its effects on soil permeability that occurs as a result of the chemical properties on the sodium ion. High sodium ion concentrations reduce the mutual attraction of soil particles, which causes them to disperse and destroys beneficial soil structure. The resultant loss in pore space restricts air and water movement within the soil profile. This phenomenon is cumulative because as soil permeability is decreased, less leaching occurs and more sodium ions are trapped in the root zone.

In assessing the sodium hazard, the ratio of sodium to calcium and magnesium ions is more significant than the actual sodium concentration because calcium and magnesium ions increase soil structure. These beneficial ions cause soil particles to attract, and the resultant flocculation increases soil porosity and permeability.

The relative proportion of sodium to other beneficial ions can be calculated in several ways. The "adjusted sodium adsorption ratio" (ASAR) was developed to include the effect of carbonate and bicarbonate ions on the ratio of sodium to calcium and magnesium (Ayers 1977). Carbonates can dissolve or precipitate calcium from soil solids and thus affect the sodium ratio.

Residual sodium carbonate (RSC) is another index of the deleterious effects of sodium on soil permeability. Sodium carbonate can dissolve soil organic matter, further destroying soil structure. RSC is computed by subtracting the sum of calcium and magnesium ions from the sum of the carbonate and bicarbonate ions in the solution (Christiansen et al. 1977).

The recommended levels for the ASAR and RSC are provided in Table 2 along with the test values for the nursery water samples. Only two nurseries had values exceeding the "good" category, which indicates that calcium and magnesium salts usually predominate over sodium in nursery irrigation waters in the Inland West.

Table 2. Soil permeability

Recommended levels:

	Good	Marginal	Poor
Adjusted sodium adsorption ratio (ASAR)[1]	<6.0	6.0-9.0	>9.0
Residual sodium carbonate (RSC)[2]	<1.25	1.25-2.50	>2.50

Nursery	Location	ASAR	RSC	Rating
Nevada State	Washoe Valley, NV	7.8	2.4	Marginal
Nevada State	Tule Springs, NV	0.9	0.0	Good
Utah State	Draper, UT	1.0	0.0	Good
Mt. Sopris	Carbondale, CO	0.2	0.0	Good
Colorado State	Ft. Collins, CO			
	1. College Lake	0.6	0.0	Good
	2. Greenhouse	0.1	0.0	Good
Albuquerque	Albuquerque, NM			
	1. Reservoir #3	1.3	0.3	Good
	2. Well #2	1.4	0.3	Good
Mountain Valley	Lincoln, NM	1.4	0.0	Good
Towner	Towner, ND	0.1	0.0	Good
Lincoln-Oakes	Oakes, ND	1.0	0.0	Good
Lincoln-Oakes	Bismarck, ND	15.7	3.8	Poor
Big Sioux	Watertown, SD	0.5	0.0	Good
Bessey	Halsey, NE	0.5	0.1	Good
Oklahoma State	Norman, OK	1.7	0.2	Good

[1] Pages 135-150 in Ayers (1977).

[2] Page 81 in USDA Salinity Lab. (1969).

Ironically, irrigation water can be too pure for proper seedling culture. Water low in dissolved salts can leach too much calcium from the soil, destroying soil structure and causing water penetration problems. An irrigation water source with approximately 1 milliequivalent (20 ppm) of calcium has been given as the minimum acceptable level (California Fertilizer Association 1975). In this survey, only the Colorado State Nursery greenhouse water falls in this category, which should not be a problem because additional calcium is injected as fertilizer.

3. Direct Ion Toxicity

Three ions have been observed to injure plant tissue directly: sodium, chloride, and boron. Sodium and chloride can be absorbed either through the foliage or by the root system. Foliage injury is particularly severe under sprinkler irrigation systems.
In general, trees and other woody perennials are sensitive to rather low concentrations of sodium and chloride compared to annual crops (Ayers 1977). Boron toxicity is hard to predict because the range between beneficial and toxic concentrations is narrow for some plants (Doneen 1975).

Only three of the irrigation waters tested in this study exceeded the safe level for toxic ions (Table 3). The Nevada State Nursery at Washoe Valley tested marginal for both sodium and boron. The Lincoln-Oakes Nursery at Bismarck had a marginal rating for boron but poor rating for sodium. The irrigation water for the Oklahoma State Nursery barely reached the marginal boron category. None of the nursery water samples had excessive ratings for chloride.

4. Alter Nutrient Availability

Saline irrigation water can change the availability and utilization of plant nutrients. This effect is particularly difficult to define because of the complicated chemical interactions in soil chemistry and seedling physiology. Excess soil calcium can chemically immobilize phosphorus in the soil and inhibit plant uptake. Iron chlorosis is a complex nutritional disease of woody plants and has been associated with an abnormal accumulation of salt ions in conifer seedling foliage (Carter 1980).

CORRECTIVE TREATMENTS

Irrigation water quality is rarely the sole cause of salinity problems but rather is one in a series of interacting conditions. Other factors such as the soil drainage, irrigation method, cultural practices, climatic conditions, and crop salt tolerance are equally important (Christiansen et al. 1977). A nursery manager must consider all these factors before designing an irrigation program. This becomes increasingly more important as water salinity increases.

1. Bare-root Nurseries

There is no economical way to treat saline irrigation water. Removal of salt ions with an ion exchange system is effective but very expensive. Water with high sodium *but low total salt levels can be treated with gypsum ($CaSO_4$) to improve its infiltration* rate (Doneen 1975), but none of the nurseries in this survey has this type of water.

Table 3. Direct ion toxicity

Recommended levels[1]:

Foliar adsorption	Good	Marginal*	Poor**
Sodium (meq/L)	<3.0	<3.0	-
Chloride (meq/L)	<3.0	<3.0	-
Root adsorption			
Sodium--adjusted sodium adsorption ratio (ASAR)	<3.0	3.0-9.0	>9.0
Chloride (meq/L)	<4.0	4.0-10.0	>10.0
Boron (mg/L)	<0.5	0.5-2.0	>2.0

Nursery	Location	Sodium (meq/L)	Sodium ASAR	Chloride (meq/L)	Boron (mg/L)
Nevada State	Washoe Valley, NV	3.5	7.8*	0.2	1.2*
Nevada State	Tule Springs, NV	0.5	0.9	0.1	0.3
Utah State	Draper, UT	0.7	1.0	0.5	0.1
Mt. Sopris	Carbondale, CO	0.1	0.2	0.0	0.0
Colorado State	Ft. Collins, CO				
	1. College Lake	0.4	0.6	0.1	0.0
	2. Greenhouse	0.2	0.1	0.0	0.0
Albuquerque	Albuquerque, NM				
	1. Reservoir #2	0.9	1.3	0.2	0.0
	2. Well #2	0.9	1.4	0.2	0.0
Mountain Valley	Lincoln, NM	1.4	1.4	1.2	0.1
Towner	Towner, ND	0.1	0.1	0.1	0.1
Lincoln-Oakes	Oakes, ND	0.8	1.0	0.3	0.2
Lincoln-Oakes	Bismark, ND	10.9	15.7**	1.3	1.4*
Big Sioux	Watertown, SD	0.4	0.5	0.2	0.0
Bessey	Halsey, NE	0.3	0.5	0.0	0.0
Oklahoma State	Norman, OK	1.4	1.7	0.2	0.5*

[1] Pages 135-150 in Ayers (1977).

Acidification of irrigation water to lower pH or improve soil infiltration rate has been accomplished by a variety of techniques. Acidification with sulfuric acid can be effective with irrigation waters containing residual sodium carbonate but is expensive, dangerous, and corrosive to irrigation equipment (Doneen 1975).

Leaching to remove excess salts from the root zone and to prevent their accumulation is the only true treatment for saline irrigation water. Chemical soil amendments with gypsum will help increase soil permeability when sodium is the predominant salt. Soils dominated by calcium can be treated with sulfur to convert insoluble calcium carbonate to the more soluble calcium sulfate form. Organic matter additions can increase soil structure and resultant porosity. Cultural practices such as deep ripping to fracture impermeable soil layers and the installation of tile drains to increase subsurface drainage have proven effective. Irrigation techniques such as applying enough water to completely saturate the soil profile and scheduling irrigation during low evaporation periods can prevent salt accumulation (Carter 1975).

2. Containerized Nurseries

Container seedling systems offer many advantages for managing irrigation water quality. Container seedlings are a higher value crop, which makes some treatments more economical, and greenhouses offer considerably more environmental control.

Although salt ion removal is still uneconomical for irrigation water, many container seedling operations acidify water to lower pH. One of the advantages of growing seedlings in containers is the ability to formulate the container potting mix for maximum permeability. Vermiculite, perlite, styrofoam beads, and other coarse materials are used to generate pore space in the rooting medium.

There are also some inherent dangers in container seedling production that relate to irrigation water quality. Because of the large amounts of irrigation water used in most greenhouses, there is a real potential for salt accumulation in the potting soil. This danger is amplified when nutrients are injected into irrigation water, because fertilizer salts add to the total salinity level. The only solution is to ensure that excess salts are leached from the potting soil during each irrigation by watering until leachage drains out the bottom of the container.

CONCLUSIONS

Irrigation water quality in tree nurseries is a function of four factors. High levels of dissolved salts can osmotically inhibit plant water uptake. The relative proportion of sodium to other ions in irrigation water can affect soil permeability. High levels of sodium, chloride, and boron can cause direct toxicity to plants through either foliage or root absorption. High calcium concentrations in the root zone can induce nutrient deficiencies by chemical inhibition of normal ion uptake and metabolism.

The best control for saline water problems is to avoid them in the first place by a comprehensive examination of water quality. Water treatments such as de-ionization are uneconomical, although gypsum or sulfuric acid amendments are sometimes used to stimulate infiltration rates. The only true solutions to saline water problems are improving and maintaining good soil structure and irrigating properly so that harmful salts are leached from the root zone.

LITERATURE CITED

Ayers, R.S. 1977. Quality of water for irrigation. J. Irrig. Drain. Div. Vol. 103, IR2. Proc. Am. Soc. Civ. Eng.: 134-154.

California Fertilizer Association. 1975. Western Fertilizer Handbook. 5th ed. Interstate Printers and Publishers, Inc. Danville, IL.

Carter, D.L. 1975. Problems of salinity in agriculture. Pages 25-35 in Poljakoff-Mayber, A. and J. Gale (eds.). Plants in Saline Environments. Springer-Verlag, Berlin.

Carter, M.R. 1980. Association of cation and organic anion accumulation with iron chlorosis of Scots pine on prairie soils. Plant Soil 56:293-300.

Christiansen, J.E., E.C. Olsen, and L.S. Wilardson. 1977. Irrigation water quality evaluation. J. Irrig. Drain. Div. Vol. 103, IR2. Proc. Am. Soc. Civ. Eng.: 155-169.

Doneen, L.D. 1975. Water quality for irrigated agriculture. Pages 56-76 in Poljakoff-Mayber, A. and J. Gale (eds.). Plants in Saline Environments. Springer-Verlag, Berlin.

Eaton, F.M. 1966. Total salt and water quality appraisal. Pages 501-509 in Chapman, H. (ed.). Diagnostic Criteria for Plants and Soils. Univ. Calif., Div. Agric. Sci., Citrus Res. Cent.

Fuller, W.H. and A.D. Halderman. 1975. Management for the control of salts in irrigated soils. Bulletin A-43. Univ. of Arizona, Tucson.

USDA Salinity Lab. 1969. Saline and alkali soils. Agric. Handbook 60:69-81.