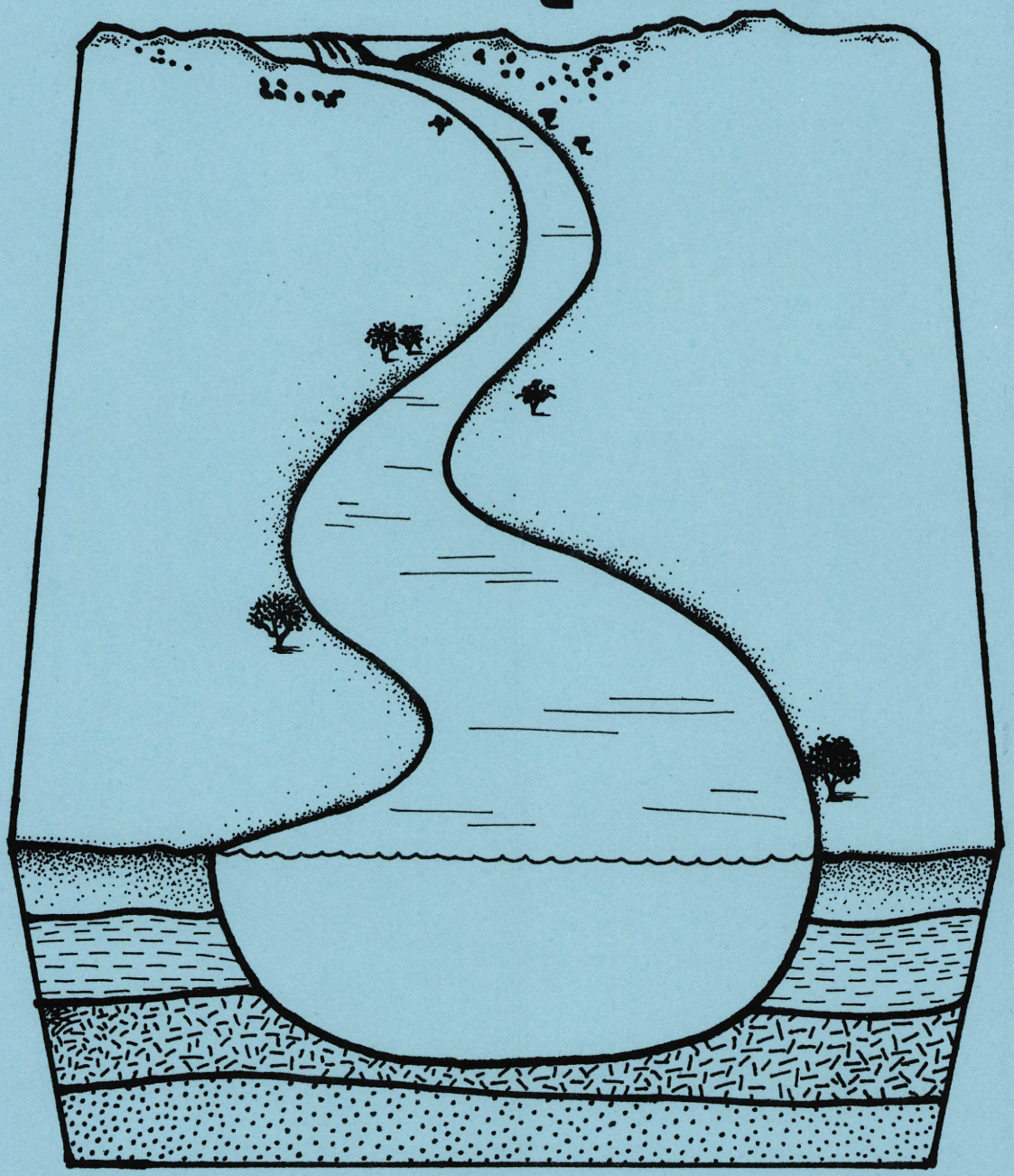
WATER QUALITY



for irrigation

WATER QUALITY FOR IRRIGATION

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All water used for irrigation contains some dissolved salts. This publication reviews the kinds and amounts of salts commonly found and their effects on soils and plants. It is written for growers who are faced with problems of water quality and soil management associated with irrigation.

The factors involved in interpreting water quality are presented as simply as possible without significantly sacrificing accuracy.

There is, however, a limit to simplification, so the serious reader must know a few chemical symbols to make some of the calculations. All terms not commonly used are explained in the text. The information has been compiled from many sources. Some of the sources are listed in the suggestions for further reading.

The user of irrigation water should know the effect of water quality on:

1. The salt content (salinity) of the soil.

2. The alkali (sodic) status of the soil.

3. The rate of water penetration into the soil.

4. The presence of elements which may be toxic to his crops.

It is difficult to isolate each of these factors from one another because some of them are interrelated.

"Reading" a Laboratory Report

Various terms and units are used in reporting a chemical analysis of water. An understanding of the commonly used methods of reporting is needed to properly interpret the data.

Dissolved salts are dissociated into electrically charged particles called ions. The ions which are positively charged are called cations (pronounced KAT-eye-uns) while the negatively charged ions are called anions. The concentration of each of these ions in the water is the usual method of reporting.

The common cations reported by laboratories are: Calcium (chemical symbol is Ca), Magnesium (Mg), Sodium (Na) and Potassium (K).

The anions usually reported are: Bicarbonate (HCO_3), Carbonate (CO_3), Chloride (Cl) and Sulfate (SO_4).

Note: This is a revised edition of an earlier leaflet. Most of this publication was written for inclusion in the "WESTERN FERTILIZER HANDBOOK" fifth edition, published in 1975 by the California Fertilizer Association, 2222 Watt Ave., Sacramento, Ca. 95825.

Substances usually found in smaller amounts are: Boron (B) and Nitrate (NO_3) which is sometimes reported as Nitrate-Nitrogen (NO_3-N).

Three principal methods are used to express the concentration of constituents in water. They are grains per gallon, parts per million and milligram equivalents per liter.

Grains per gallon uses the English system of units. Most laboratories no longer use this method for irrigation water. It is still used to report hardness of water. To change grains per gallon to parts per million, multiply by 17.2.

Parts per million (ppm) is defined as one part of a salt to one million parts of water - or one milligram per kilogram of solution. Water analyses are usually reported on a volume basis. One liter (1.057 quart) of water weighs 1 kilogram (1000 grams or 2.2 pounds), therefore, one milligram (one thousandth of a gram) per liter is one part per million.

PPM is used to report boron, nitrates, nitrate-nitrogen and a few other minerals found in relatively small amounts.

Milliequivalents per liter (me/l) is the most meaningful method of reporting the major constituents of water. This is a measure of the chemical equivalence of an ion.

Salts are made up of a combination of cations (sodium, calcium, magnesium, etc.) and anions (chlorides, sulfates, bicarbonates, etc.). These cations and anions combine in definite weight ratios. For example, common baking soda, sodium bicarbonate ($NaHCO_3$) is made up of 23 parts of sodium combined with 61 parts of bicarbonate -- or one sodium cation is combined with one bicarbonate anion to form a total of 84 parts. If 84 grams 84 grams of baking soda are dissolved in one liter of water, the solution is said to contain one equivalent per liter.

A milliequivalent is one-thousandth of an equivalent or 0.084 grams per liter. If sodium were combined with chloride to form common table salt (NaCl) it would take 23 grams of sodium and 35.5 grams of chloride to make 58.5 grams of the salt making one equivalent, or 0.0585 grams to make one milliequivalent. (see Table 1 for the approximate equivalent weights of the common ions).

Some laboratories report the common constituents in parts per million (milligrams per liter). To convert to milliequivalents per liter divide the ppm by the equivalent weight of an ion. For example, a laboratory reports 54 ppm of sulfate. The equivalent weight of sulfate found in Table 1 is 48. Divide 54 by 48 and find the water has 1.12 me/l of sulfate.

The pH expresses the acidity or alkalinity of water. A pH reading of less than 7.0 is acidic, 7.0 is neutral, and above 7.0 is on the alkaline side.

Most well waters range from pH 7.0 to pH 8.5. Some stream waters may be as acidic as pH 6.5.

The pH measurement is not important if the major ions are reported and is often omitted from laboratory reports.

Total salt content is usually reported as the electrical conductivity (EC). Chemically pure water does not conduct electricity but water with salts dissolved in it does. The more salt in the water, the better conductor it becomes. The ability of a water sample to conduct electricity is used to determine its salt content. EC is usually reported as millimhos per centimeter (mmhos/cm).

The total salt content or total dissolved solids (TDS) is usually reported as ppm. This can be approximated by evaporating a known weight of water sample to dryness and weighing the salt remaining. More often it is approximated by measuring the EC in mmhos/cm and multiplying by 640. This gives the total dissolved solids in ppm. If a water has an EC of 1.6, then 1.6 x 640 - 1024 ppm total dissolved solids. The me/l of total salts can be closely estimated by multiplying the EC in mmhos/cm by 10. For example, a water with an EC of 2.62 mmhos/cm contains 26.2 me/l of total salts.

Electrical conductivity is commonly used to check the salt content of soils. The conductivity is measured on the saturation extract from the soil and is designated EC_e. This is used to monitor the changes in the salt content of the soil resulting from irrigation. It is also useful in evaluating the relative tolerance of plants to salt and the suitability of a soil for certain crops.

Percent Sodium is sometimes used. It is the percent of the total cations in milliequivalents which is sodium. A high sodium percentage may indicate a poor quality water but in recent years more refinement in interpretation of water quality has made this less useful.

Soil Properties and Water Quality

Over a long period of time the quality of irrigation water and the irrigation practice reach an equilibrium with the soil.

The Cations

To a great extent, the cations determine the physical as well as the chemical properties of soil. The cations of most concern are Calcium, Magnesium, Sodium and Potassium.

Calcium (Ca) is found to some extent in all natural waters. A soil predominantly saturated with calcium is friable and easily worked, usually permits water to penetrate easily and does not puddle or run together when wet. For this reason calcium in the form of gypsum is often applied to "tight" soils to improve the physical properties. Generally, an irrigation water containing predominantly calcium is desirable.

Magnesium (Mg) is also usually found in measurable amounts. Magnesium behaves much like calcium in the soil. Often laboratories will not separate calcium and magnesium but will report simply Ca + Mg in me/l. For most purposes this is adequate.

Sodium (Na) salts are all very soluble and as a result are found in all natural waters.

A soil with a large amount of sodium associated with the clay fraction has poor physical properties for plant growth. When wet it runs together, becomes sticky and is nearly impervious to water. When it dries, hard clods form, making it difficult to till. Continued use of waters with a high proportion of sodium may bring about these severe changes in an otherwise good soil. Eventually these soils may become alkali. The so-called "slick spots" are usually spots high in exchangeable sodium.

The process of making soils alkali can be reversed by applying soluble calcium (usually gypsum) to the soil or into the irrigation water. Calcium replaces the sodium on the soil particles so that it may be leached below the root zone.

Potassium (K) is usually found in only small amounts in natural waters. It behaves much like sodium in the soil. It is not often reported separately in water analyses but is included with the sodium.

The Anions

The anions indirectly have an effect on the physical properties of soil by altering the ratio of calcium and sodium attached to the clays. The important anions are bicarbonate, carbonate, chloride, and sulfate.

Bicarbonate (HCO_3) is common in natural waters. It is not usually found in nature except in solution. Sodium and potassium bicarbonates can exist as solid salts; for example, baking soda (sodium bicarbonate). Calcium and magnesium bicarbonates exist only in solution. As the moisture in the soil is reduced, either by removal by plants or by evaporation, calcium bicarbonate decomposes, carbon dioxide (CO_2) goes off into the air and water (H_2O) is formed leaving insoluble lime ($CaCO_3$) behind.

$$Ca(HCO_3)_2 \xrightarrow{\text{upon drying}} CaCO_3 + CO_2 + H_2O$$

A similar reaction takes place with magnesium bicarbonate.

Large amounts of bicarbonate ions in irrigation water will, as the soil approaches dryness, precipitate calcium thereby removing it from the clay. This leaves sodium in its place. In this way a calcium-dominant soil can become a sodium-dominant (sodic) soil by the use of a high bicarbonate irrigation water.

Carbonate (CO_3) is found in some waters. Since calcium and magnesium carbonates are relatively insoluble, high carbonate waters mean that the cations associated with them are likely to be sodium with possibly a small amount of potassium. Upon drying in the soil, the carbonate ion will remove calcium and magnesium from the clay similar to bicarbonate and an alkali (sodic) soil will develop.

Chloride (Cl) is found in all natural waters. In high concentrations it is toxic to some plants. All common chlorides are soluble and contribute to the total salt content (salinity) of soils. The chloride content must be determined to properly evaluate irrigation waters.

Sulfate (SO_4) is abundant in nature. Sodium, magnesium and potassium sulfates are readily soluble. Calcium sulfate (gypsum) has a limited solubility. Sulfate has no characteristic action on the soil except to contribute to the total salt content. The presence of soluble calcium will limit its solubility.

Nitrate (NO_3) is not commonly found in large amounts in natural waters. Even small amounts can affect its use as irrigation water by supplying plants with more than the desired amount of this plant nutrient. High nitrates in water may indicate contamination from excessive use of fertilizers or from sewage. Nitrates, however, have no effect on the physical properties of soil except to contribute slightly to its salinity.

Boron (B) occurs in water in one or another anion form. The usual range in natural waters is from 0.01 ppm to 10 ppm. Concentrations greater than this are known but are most often from hot springs or brines.

Boron has no measurable effect on the physical properties of soil in the amounts that can be tolerated by plants. Boron is not as readily removed from the soil as chloride or nitrate but most of it can be removed by successive leachings.

A small amount of boron is essential for plant growth but a concentration slightly above the optimum is toxic to plants. Some plants are more sensitive to an excess than others. Plants grown on some sandy soils which have been irrigated for several years by water exceedingly low in boron (less than 0.02 ppm) may develop boron deficiency.

Classifying Irrigation Water

An ideal classification scheme should predict the effect of irrigation water on soils and plant growth. Many methods have been devised -- all have been useful if not applied too broadly, but none has been completely satisfactory. It is doubtful if any system can be completely satisfactory without knowing how much water is applied, how much is

leached below the root zone, the sensitivity of the crops to the various dissolved minerals, the frequency of irrigation, soil properties and even climatic conditions.

Some people confuse saline and alkali (sodic) soils. This confusion came about in part by the old terms of "white" alkali and "black" alkali. If use of these terms were stopped much of the confusion would cease.

A saline soil is a soil containing soluble salts in such quantities that they interfere with the growth of crops. A saline soil is a non-alkali soil.

An alkali soil is a soil which contains enough sodium attached to the clay particles to interfere with the growth of crops. If an alkali soil is relatively free of soluble salts it is called a non-saline alkali soil. If, in addition to being alkali, it has sufficient soluble salts to restrict plants it is called a saline-alkali soil.

In the old terminology "white" alkali was a saline soil and "black" alkali was an alkali soil. There was no satisfactory term where both conditions existed.

Salinity Hazard - One of the hazards of irrigated agriculture is the possible accumulation of soluble salts in the root zone. Some plants can tolerate more salts than others but all plants have a maximum tolerance. With reasonably good irrigation practices the salt content of the saturation extract of soil is 1.5 to 3 times salt content of the irrigation water. Where ample water is used to remove excess salt from the root zone, the salt level in the saturation extract is about 1.5 times that of the irrigation water. Where water is used more sparingly, there may be 3 times as much salt.

An acre-foot of water (the amount of water covering one acre, one foot deep) weighs approximately 2,720,000 pounds; therefore, 1 ppm of a salt in an acre-foot of water weighs 2.72 pounds. This means that one acre-foot of water containing only 735 ppm (EC = 1.15 mmhos/1) carries one ton of salt!! Many growers apply 4 feet of irrigation water per year to produce a crop -- or they apply 4 tons of salt on every acre every year!! This points out the need for adequate leaching below the root zone.

With ordinary irrigation methods there is some leaching, hence the accumulation of salts in the soil water is reduced but not eliminated. Before a critical assessment of the salinity hazard of any irrigation water is made, it is necessary to know how much salt the crop can tolerate and how much leaching is needed to maintain the desired salt level in the soil water.

Recent research at the U. S. Salinity Laboratories at Riverside, California has shown that plants can tolerate a higher salt content in the lower root zone than was previously believed possible, hence the leaching requirement (percent of water needed for leaching) may be reduced. Tables 2a, 2b, 2c, and 2d show the crop tolerance and leaching requirements estimated for several crops. Leaching need not be done at each irrigation but should be done probably at least once a year.

Growers rotating crops must provide enough leaching so that damage to the most salt sensitive crop in the rotation will be at a minimum.

With reasonable irrigation practices, there should be no salinity problems with irrigation water with an EC of less than 0.75 mmhos/cm. Increasing problems can be expected between EC 0.75 and 3.0 mmhos/cm. An EC greater than 3.0 will cause severe problems except for areas restricted only to a few salt tolerant crops.

It has generally been assumed that the effects of a saline water could be offset by increasing the amount of leaching so that the average salt content of the root zone would not be increased. The U. S. Salinity Laboratory has demonstrated that yields of alfalfa (and probably other crops) is governed not by average soil salinity but primarily by the salinity of the irrigation water. Yields were reduced as the salinity of the water increased no matter how much leaching was done. With this in mind, the practice of blending saline drain waters with low salt irrigation waters needs to be reassessed.

Sodium or Permeability Hazards. In most cases permeability of water becomes a hazard before sodium as such affects plant growth. In a few plants, notably avocados, this may not be strictly true.

As the proportion of sodium attached to the clay in the soil increases, the soil tends to disperse or "run together" bringing about reduced rates of water penetration. The sodium adsorption ratio (SAR) indicates the relative activity of sodium ions as they react with clay. From the SAR the proportion of sodium on the clay fraction of the soil can be estimated when an irrigation water has been used for a long period of time with reasonable irrigation practice.

Most laboratories will report the SAR of irrigation waters. If not, it can be simply determined by using the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

The sodium (Na), Calcium (Ca) and Magnesium (Mg) are expressed in milliequivalents per liter (me/l).

A refinement of the SAR called the "Adjusted SAR" (SARa) has recently been developed. Some laboratories are now reporting SARa and hopefully all will shortly adopt this reporting procedure. SARa includes the added effects of precipitation and mineralization of calcium in soils as related to $CO_3 + HCO_3$ concentrations.

To evaluate the sodium or permeability hazard:

$$* \; SARa = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \left[1 + (8.4\text{-}pHc)\right]$$

$$\text{or } SARa = SAR \left[(1 + (8.4 - pHc)\right]$$

pHc is a calculated value based on total cations, Ca + Mg and $CO_3 + HCO_3$ in the water.

If the SARa is less than 6.0 there should be no problems with either sodium or permeability. In the range of 6.0 to 9.0 there are increasing problems. If the SARa is greater than 9.0, severe problems can be expected.

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* Tables for calculating pHc values of water are found in Table 4. For details of this somewhat involved calculation see an article by J. D. Rhoades, 1972. Quality of water for irrigation. Soil Science 113:277-284.

The SARa can be reduced by:

1. Increasing the calcium content of the water by adding gypsum or some other soluble calcium salt.

2. Reducing the HCO_3 in the water by adding sulfuric acid, sulfur dioxide (SO_2) or some other acidifying amendment.

Bicarbonate in irrigation water is particularly troublesome. The SARa is a good index of the sodium and permeability hazard if the water passes through the soil and reaches equilibrium with it. Unfortunately, in the field this is not always the case. Water with relatively high bicarbonate and low calcium and magnesium content would have a high SARa and hence an exceedingly slow permeability.

In many cases, plant growth will not permit water to remain on the crop long enough to allow for deep leaching. As evaporation and plants remove moisture from the soil, the soil water becomes more concentrated and excess bicarbonate will remove calcium and magnesium from the soil forming insoluble carbonates. Sodium thereby replaces the calcium and magnesium on the soil and further aggravates the permeability problem. Without adequate leaching the soil will not only become saline but will also become alkali (sodic).

A measure of this carbonate-bicarbonate factor is found in the "Residual Sodium Carbonate" or simply RSC. Many laboratories calculate and report the RSC. It may be calculated easily by the following equation:

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

The concentrations of all ions are in me/l as is the RSC.

The RSC has lost favor for critically evaluating the sodium or permeability hazard of water but is still useful for a quick assessment. Usually an RSC of less than zero is most desirable. An RSC of 0 to 1.25 me/l is probably safe but the water should be used carefully. An RSC from 1.25 to 2.50 me/l is high and should probably be used only with an appropriate soil or water amendment.

Above 2.50 me/l trouble is almost certain to develop. If this water must be used it should be used with utmost care. There are cases where sodium or permeability problems develop using water with a zero or low RSC. For this reason the SARa is a more consistent index of the hazard.

Reducing the excess water used for leaching as has been suggested for saline waters may possibly create severe problems when applied to the use of water containing relatively large concentrations of CO_3 and HCO_3. This aspect has not yet been fully studied.

Irrigation water with a very low salt content may also present a water penetration problem. In this case the addition of some salt, preferably a calcium salt such as gypsum, would be helpful. There is good evidence that all irrigation waters should contain a minimum of 20 ppm of calcium (1.0 me/l) to prevent dispersion of the soil. The EC of the water should be over 0.5 mmhos/cm.

Toxic Constituents

There are several elements found in natural waters which can be toxic to plants. Boron, chlorides, and sodium are the only ones commonly found. Waters high in bicarbonates have been shown to induce iron deficiencies in some plants but this is minor when compared to its role in creating permeability problems.

Boron Hazard

A small amount of boron is necessary for plant growth. It has been said that 0.02 ppm B or more in the irrigation water may be required to sustain an adequate supply of this plant nutrient. Except for waters diverted from some rivers, the major problem is an excess of boron. The following ranges provide a satisfactory guide to the boron hazard in the irrigation water.

Below 0.5 ppm - satisfactory for all crops.
0.5 - 1.0 ppm - satisfactory for most crops; sensitive crops may show injury (may show leaf injury but yields may not be affected).
1.0 - 2.0 ppm - satisfactory for semi-tolerant crops. Sensitive crops are usually reduced in yield and vigor.
2.0 ppm and over - only tolerant crops produce satisfactory yields.

See Table 3 for crop sensitivity.

Plants grown in soils high in lime may tolerate more boron than those grown in non-calcareous soils.

Chloride Hazard

Chlorides are found in all natural waters. The common chlorides are soluble and are not fixed in the soil so that they can move through the soil and into the drainage water. Chlorides are necessary for plant growth in relatively small amounts. In high concentrations, however, chlorides will inhibit plant growth and they are specifically toxic to some plants.

Most annual crops and short-lived perennials are moderately to highly tolerant to chlorides and growers can rely on the salinity hazard index for evaluating water use problems. Trees, vines, and woody ornamentals are sensitive to chlorides. For those plants the following index may serve as a guide:

Chlorides (me/l)	Chlorides (ppm)	Notes
Less than 2	Less than 70	Generally safe for all plants
2-4	70 - 140	Sensitive plants usually show slight to moderate injury.
4-10	140 - 350	Moderately tolerant plants usually show slight to substantial injury.
Greater than 10	Greater than 350	Severe problems.

Sodium Toxicity

Trees, vines, and woody ornamentals may be sensitive to excessive sodium absorbed through the plant roots. As in the case of chlorides, annual crops are usually not

affected except as a contribution to total salt content. Water with SARa below 3 there is no problem; from SARa 3 to 9 problems increase and above 9 they are severe. With waters this high, severe permeability problems would also exist.

Water for Sprinkler Irrigation

Most water suitable for surface irrigation may be safely used for overhead sprinkler irrigation. There are, however, some exceptions. Leaf burn caused by sodium and chloride absorption may occur when the rate of evaporation is high. Conditions of low humidity, high temperature and winds can increase the concentration of these ions in the water on the leaves between rotations of the sprinklers. Sometimes this can be corrected by increasing the rate of rotation. If this is impractical it may be necessary to irrigate only at night during periods of hot, dry weather. Usually no problem is found when the irrigation water contains 3 me/l or less of either sodium or chloride.

Bicarbonate ions in water can also be a problem with overhead sprinkler irrigation. A white deposit of calcium carbonate forms on the leaves and fruit. This can render some fruits and ornamentals unmarketable because they are unattractive. This coat of "whitewash" is not known to have any other adverse effect on plant growth. Levels below 1.5 me/l of HCO_3 should cause no problem. Increasing problems occur between 1.5 and 8.5 me/l and severe problems are found above 8.5 me/l. At this high level of HCO_3 most waters are unfit for irrigation for other reasons.

Summary - The following table summarizes the limits which were discussed in the text.

Problem	Degree of Problem		
	None	Increasing	Severe
Salinity			
EC (mmhos/cm)	< 0.75	0.75 - 3.0	> 3.0
TDS (ppm)	< 480	480 - 1920	> 1920
Permeability			
Caused by low salt:			
EC (mmhos/cm)	> 0.50	0.50 - 0	-
TDS (ppm)	> 320	320 - 0	-
Caused by sodium:			
SARa	< 6	6 - 9	> 9
Toxicity			
From root absorption:			
Sodium (SARa)	< 3	3 - 9	> 9
Chloride (me/l)	< 4	4 - 10	> 10
(ppm)	< 140	140 - 350	> 345
Boron (ppm)	< 0.5	0.5 - 2	> 2
Toxicity			
From leaf absorption (sprinklers)			
Sodium (me/l)	< 3	> 3	
(ppm)	< 70	> 70	
Chloride (me/l)	< 3	> 3	
(ppm)	< 100	>100	
Miscellaneous			
Excess nutrient:			
Nitrate-nitrogen (ppm)	< 5	5 - 30	> 30
"Whitewashing"			
Bicarbonate (me/l)	< 1.5	1.5 - 8.5	> 8.5

Table 1.

Major Constituents in Irrigation Water

Ion Name	Symbol	Approximate Equivalent Weight
Calcium	Ca	20
Magnesium	Mg	12
Cations		
Sodium	Na	23
Potassium	K	39
Bicarbonate	HCO_3	61
Carbonate	CO_3	30
Anions		
Chloride	Cl	35.5
Sulfate	SO_4	48

Table 2.

CROP SALINITY TOLERANCE AND LEACHING REQUIREMENT

The following tables show:

1. The yield reduction to be expected due to salinity of irrigation water (EC_w).
2. The salt content of the soil saturation extract (EC_e) when common surface irrigation methods are used.
3. The leaching requirement (LR) means the fraction of the irrigation water that must be leached through the active root zone to control salinity at a specified level.
4. The maximum concentration of salts that can occur in the drainage water (EC_{dw}) under the crops due to evaporation and removal by plants.

These tables are from data in USDA Agricultural Information Bulletin 283 and unpublished data from Dr. Leon Bernstein, U. S. Salinity Laboratory, Riverside, California. Compiled by R. L. Branson and R. S. Ayers, Extension Soils and Water Specialists, Agric. Ext. Serv., University of California.

Table 2a

FIELD CROPS

Reduction in Yield

Crop	0%			10%			25%			50%			Maximum
	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECdw
Barley	8	5.3	12%	12	8	18%	16	10.7	24%	18	12	27%	44
Sugar Beets	6.7	4.5	11%	10	6.7	16%	13	8.7	21%	16	10.7	26%	42
Cotton	6.7	4.5	11%	10	6.7	16%	12	8	19%	16	10.7	26%	42
Safflower	5.3	3.5	12.5%	8	5.3	19%	11	7.3	26%	14	8	28.5%	28
Wheat	4.7	3.1	8%	7	4.7	12%	10	6.7	17%	14	9.3	23%	40
Sorghum	4	2.7	7.5%	6	4	11%	9	6	17%	12	8	22%	36
Soybean	3.7	2.5	10%	5.5	3.7	14%	7	4.7	18%	9	6	23%	26
Rice (paddy)	3.3	2.2	9%	5	3.3	14%	6	4	16%	8	5.3	22%	24
Corn	3.3	2.2	12%	5	3.3	18%	6	4	22%	7	4.7	26%	18
Sesbania	2.7	1.8	7%	4	2.7	10%	5.5	3.7	14%	9	6	23%	26
Broadbean	2.3	1.5	8%	3.5	2.3	13%	4.5	3	17%	6.5	4.3	24%	18
Flax	2	1.3	7%	3	2	11%	4.5	3	17%	6.5	4.3	24%	18
Beans (field)	1	.7	6%	1.5	1	8%	2	1.3	11%	3.5	2.3	19%	12

Table 2b

VEGETABLE CROPS

	Reduction in Yield												
	0%			10%			25%			50%			Maximum
Crop	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECdw
Beets	5.3	3.5	11%	8	5.3	17%	10	6.7	21%	12	8	25%	32
Spinach	3.7	2.5	12.5%	5.5	3.7	18.5%	7	4.7	23.5%	8	5.3	26.5%	20
Tomato	2.7	1.8	8%	4	2.7	12%	6.5	4.3	19.5%	8	5.3	24%	22
Broccoli	2.7	1.8	7%	4	2.7	10%	6	4	15%	8	5.3	20%	26
Cabbage	1.7	1.1	4%	2.5	1.7	6.5%	4	2.7	10%	7	4.7	18%	26
Potato	1.7	1.1	5.5%	2.5	1.7	8.5%	4	2.7	13.5%	6	4	20%	20
Sweet Corn	1.7	1.1	5.5%	2.5	1.7	8.5%	4	2.7	13.5%	6	4	20%	20
Sweet Potato	1.7	1.1	5.5%	2.5	1.7	8.5%	3.5	2.3	11.5%	6	4	20%	20
Lettuce	1.3	.9	5%	2	1.3	7%	3	2	11%	5	3.3	18%	18
Bell Pepper	1.3	.9	5%	2	1.3	7%	3	2	11%	5	3.3	18%	18
Onion	1.3	.9	7.5%	2	1.3	11%	3.5	2.3	19%	4	2.7	22.5%	12
Carrot	1	.7	6%	1.5	1	8%	2.5	1.7	14%	4	2.7	22.5%	12
Beans	1	.7	7%	1.5	1	10%	2	1.3	13%	3.5	2.3	23%	10
Cantaloupe *	2.3	1.5	8%	3.5	2.3	12%	No data			No data			-
Watermelon *	2	1.3	8%	No data			No data			No data			-

* Assumes ECdw = 20 similar to potato.

Table 2c

FRUIT CROPS
Reduction in Yield

Crop	0%			10%			50% 1/			Maximum
	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECdw
Date Palm	5.3	3.5	7%	8	5.3	11%	16	10	21%	48
Fig Olive Pomegranate	2.7-4.0	1.8-2.7	6-10%	4.6	2.7-4.0	10-14%	9	6	21%	28
Grape (Thompson)	2.7	1.8	7.5%	4	2.7	11%	8	5.3	22%	24
Grapefruit Orange Lemon	1.7	1.1	7%	2.5	1.7	11%	5	3.3	33%	16
Apple Pear	1.7	1.1	7%	2.5	1.7	11%	5	3.3	33%	16
Almond Apricot Peach Prune	1.7	1.1	7%	2.5	1.7	11%	5	3.3	33%	16
Walnut	1.7	1.1	7%	2.5	1.7	11%	5	3.3	33%	16
Blackberry Boysenberry Raspberry	1.0-1.7	0.7-1.1	5-8%	1.5-2.5	1.0-1.7	7-12%	4	2.7	19%	14
Avocado	1.3	0.9	7.5%	2	1.3	11%	4	2.7	22.5%	12
Strawberry	1.0	0.7	7%	1.5	1.0	10%	3	2.0	20%	10

1/ Calculated values, assuming 50% decrease in yield results from doubling of salinity values for 10% yield decrement.

Table 2d

FORAGE CROPS

Reduction in Yield

Crop	0%			10%			25%			50%			Maximum
	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECe	ECw	LR	ECdw
Bermuda Grass	8.7	5.8	13%	13	8.7	20%	16	10.7	24%	18	12	27%	44
Tall Wheat Grass	7.3	4.9	11%	11	7.3	17%	15	10	23%	18	12	27%	44
Crested Wheat Grass	4	2.7	6%	6	4	9%	11	7.3	17%	18	12	27%	44
Tall Fescue	4.7	3.1	8%	7	4.7	12%	10.5	7	17.5%	14.5	9.7	24%	40
Barley (hay)	5.3	3.5	10%	8	5.3	15%	11	7.3	20%	13.5	9	25%	36
Perennial Rye	5.3	3.5	10%	8	5.3	15%	10	6.7	19%	13	8.7	24%	36
Harding Grass	5.3	3.5	10%	8	5.3	15%	10	6.7	19%	13	8.7	24%	36
Birdsfoot Trefoil	4	2.7	10%	6	4	14%	8	5.3	19%	10	6.7	24%	28
Beardless Wild Rye	2.7	1.8	6%	4	2.7	10%	7	4.7	17%	11	7.3	26%	28
Alfalfa	2	1.3	5%	3	2	7%	5	3.3	12%	8	5.3	19%	28
Orchard Grass	1.7	1.1	4%	2.5	1.7	6.5%	4.5	3	11.5%	8	5.3	20%	26
Meadow Foxtail	1.3	.9	4%	2	1.3	5%	3.5	2.3	10%	6.5	4.3	18%	24
Clover	1.3	.9	6%	2	1.3	9%	2.5	1.7	12%	4	2.7	19%	14

An example of how to use these tables. Assume the crop is corn:

From the tables:

Maximum EC_{dw} = 18 mmho

Maximum EC_w:

for 0 yield loss = 2.2 mmho/cm

10% " " = 3.3 mmho/cm

25% " " = 4.0 mmho/cm

50% " " = 4.7 mmho/cm

Suppose your water has an EC_w = 2.7. Using the common surface irrigation methods you can expect that the EC_e of the most active root zone to be 1.5 times the EC_w (2.7) or 4.0 mmho/cm. The tables show that you can expect a decrease in yield of slightly less than 10%.

In order to maintain the EC_{dw} at the maximum allowable you would need a leaching requirement (LR) of 15%.

This is calculated by substituting in the equation:

$$LR = \frac{EC_w}{EC_{dw}} \times 100 = \frac{2.7}{18} \times 100 = 15\%$$

Table 3

RELATIVE TOLERANCE OF PLANTS TO BORON

(In each group the plants first named are considered as being more sensitive and the last named more tolerant)

SENSITIVE	SEMI-TOLERANT	TOLERANT
0.5 ppm	1 ppm	2 ppm
Lemon	Lima bean	Carrot
Grapefruit	Sweet potato	Lettuce
Avocado	Bell pepper	Cabbage
Orange	Tomato	Turnip
Thornless blackberry	Pumpkin	Onion
Apricot	Zinnia	Broad bean
Peach	Oat	Gladiolus
Cherry	Milo	Alfalfa
Persimmon	Corn	Garden beet
Kadota fig	Wheat	Mangel
Grape (Sultanina & Malaga)	Barley	Sugar beet
Apple	Olive	Palm (Phoenix Canariensis)
Pear	Ragged robin rose	Date palm (Phoenix Dactylifera)
Plum	Field pea	Asparagus
American elm	Radish	Athel (Tamarix Aphylla)
Navy bean	Sweet pea	
Jerusalem artichoke	Pima cotton	
Persian (English) walnut	Acala cotton	
Black walnut	Potato	
Pecan	Sunflower (native)	
1 ppm	2 ppm	4 ppm

Adopted from USDA
Tech. Bul. #448

Table 4 CONDENSED TABLES FOR CALCULATING pHc VALUES OF WATERS

pHc can be calculated, using the table below; pHc = $(pK_2'-pK_c')$ + p (Ca + Mg) + pAlk
where $pK_2'-pK_c'$ is obtained from Ca + Mg + Na
p (Ca + Mg) is obtained from Ca + Mg
pAlk " " " $CO_3 + HCO_3$

Tables for Calculation pHc

Conct. Ca + Mg + Na (me/l)	$p(K_2'-K_c')$	Conct. Ca + Mg (me/l)	p(Ca + Mg)	Conct. $CO_3 + HCO_3$ (me/l)	pAlk
.5	2.11	.05	4.60	.05	4.30
.7	2.12	.10	4.30	.10	4.00
.9	2.13	.15	4.12	.15	3.82
1.2	2.14	.2	4.00	.20	3.70
1.6	2.15	.25	3.90	.25	3.60
1.9	2.16	.32	3.80	.31	3.51
2.14	2.17	.39	3.70	.40	3.40
2.8	2.18	.50	3.60	.50	3.30
3.3	2.19	.63	3.50	.63	3.20
3.9	2.20	.79	3.40	.79	3.10
4.5	2.21	1.00	3.30	.99	3.00
5.1	2.22	1.25	3.20	1.25	2.90
5.8	2.23	1.58	3.10	1.57	2.80
6.6	2.24	1.98	3.00	1.98	2.70
7.4	2.25	2.49	2.90	2.49	2.60
8.3	2.26	3.14	2.80	3.13	2.50
9.2	2.27	3.90	2.70	4.0	2.40
11	2.28	4.97	2.60	5.0	2.30
13	2.30	6.30	2.50	6.3	2.20
15	2.32	7.90	2.40	7.9	2.10
18	2.34	10.00	2.30	9.9	2.00
22	2.36	12.50	2.20	12.5	1.90
25	2.38	15.80	2.10	15.7	1.80
29	2.40	19.80	2.00	19.8	1.70
34	2.42				
39	2.44				
45	2.46				
51	2.48				
59	2.50				
67	2.52				
76	2.54				

Example: To calculate SARa of water from

$$SARa = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \left[1 + (8.4-pHc)\right]$$

With report of water analysis
Na = 3.5 me/l
Ca+Mg = 1.6 me/l
Ca+Mg+Na = 5.1 me/l
CO_3+HCO_3 = 3.0 me/l

pHc = 2.22 + 3.1 + 2.5 = 7.82 (from tables)

$$SARa = \frac{3.5}{\sqrt{\frac{1.6}{2}}} \left[1 + (8.4-7.82)\right] = 3.91\ (1 + 0.58)$$

SARa = 6.2

NOTE: Values of pHc above 8.4 indicate tendency to dissolve lime from soil through which the water moves; values below 8.4 indicate tendency to precipitate lime from waters applied. (ref: L. V. Wilcox, U. S. Salinity Laboratory, mimeo Dec. 30, 1966)

SUGGESTIONS FOR FURTHER READING

1. USDA Handbook No. 60.

   Diagnosis and Improvement of Saline and Alkali Soils, 1954

2. USDA Information Bulletins

   No. 205 (1959) Salt Tolerance of Vegetable Crops.

   No. 283 (1964) Salt Tolerance of Plants.

   No. 282 (1965) Salt Tolerance of Fruit Crops.

3. D. R. Nielsen, J. W. Biggar, R. J. Miller, 1964 - Water Management for Salinity Control, Calif. Agric. Vol. 18, No. 8, pp 405.

Some more technical aspects of water quality are discussed in the following papers and should be studied by professional consultants.

4. Bernstein, L. and L. E. Francois, 1973. Sensitivity of Alfalfa to Salinity of Irrigation and Drainage Water. Soil Sci. Soc. Amer, Proc. 37:931-943.

5. Bower, C. A., G. Ogata, and J. M. Tucker, 1968. Sodium Hazard of Irrigation Waters as Influenced by Leaching Fraction and by Precipitation or Solution of Calcium Carbonate. Soil Sci. 106:29-34.

6. Rhoades, J. D., Quality of Water for Irrigation. 1972. Soil Sci. 113:277-284.

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