WATER QUALITY AND SOIL SALINITY GUIDELINES

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It is the nature of irrigated agriculture to apply water to lands in order to supplement the available water stored in the soil to produce crops of acceptable yield and quality. Irrigation is common practice in California and other arid and semi-arid regions of the world. Salt problems commonly occur in regions of this type which can lower the productivity of extensive areas of agricultural land.

Traditionally, agriculture has been practiced on soils which were free of troublesome salts. Undoubtedly, more irrigable lands would be in production if it were not for the uncertainties resulting from the development of salt-affected soils. Recently, however, salt-affected lands are being developed at an increasing rate.

Salt-affected soils have excessive amounts of soluble salts (saline), adsorbed sodium (alkali), or both (saline-alkali). The original sources of these salts are the exposed rocks and minerals of the earth's crust. As a result of chemical and physical weathering, salts are gradually released. In humid areas these soluble salts are carried downward through the soil profile by rain, and ultimately are transported to the oceans. In arid regions, however, leaching is not as effective and the salts may not be transported far due to the lack of adequate rainfall. High evaporation and transpiration rates also tend to concentrate salts by decreasing the water available for leaching.

The type of salts adversely affecting crop production when present in high amounts (i.e., boron, chloride, sodium, bicarbonate) are most often the result of the type of materials from which the soil was formed. Generally, soils on the west side of the San Joaquin River developed from materials formed from marine sediments which were high in salts. Soils of the east side of the San Joaquin River are formed of granitic materials which are relatively low in harmful salts.

Salts also may be imported into an area via irrigation water, be it a surface or well source. All irrigation water contains salts to a lesser or greater degree. Many times irrigation waters are the major source of salt accumulation in the root zone.

Salt levels can be controlled in order to sustain crop yields through management practices designed to control or remove salts from the root zone. Saline conditions can be made worse by the lack of drainage. Poor drainage can result in a high water table, or the accumulation of salts in areas which collect drain water. Salts can "wick up" through capillary action from a shallow water table further salinizing the root zone.

Soil salinization can also occur in soils initially low in salts which are irrigated with good quality water if salts concentrated by crop use and evaporation are not leached out of the soil.

Fertilizer salt additions to soils can cause minor increases in total salts, which at times can cause crop damage when they are concentrated near the surface. Generally, this has its greatest effect during the germination-through-seedling stage of crop growth.

Irrigation water quality refers to its suitability for use. A good quality water has the potential to allow maximum yield under good soil and management practices. With poor quality water, soil and cropping problems can be expected to develop, causing reduced yields unless special management practices are utilized to maintain or restore productivity.

The suitability of a water is determined by its potential to cause problems. Problems caused are often complex but generally fall into four categories--salinity, permeability, toxicity and miscellaneous--each of which may act singularly or in combination to affect crop production.

1. Salinity. A salinity problem related to water quality occurs if the total quantity of salts in the irrigation water is high enough that salts accumulate in the crop root zone to the extent that yields are affected. Excessive quantities of soluble salts in the root zone result in increased difficulty of water uptake by the crop. Reduced water uptake by the plant can result in slow or reduced growth. Symptoms of this salt-induced water stress are similar in appearance to those of drought, such as early wilting.

Salts build up in the soil by a process of concentration. Salts are moved by water both brought in and carried away. Thus, irrigation water and rain both play an important role in the salt budget of the soil. Irrigation waters bring salts into the root zone; the crop removes only a small portion of the salt and a large portion of the water. The result is that salts are left behind to build up if excess irrigation water or rain is not applied to leach salts out of the root zone.

2. Permeability. A permeability or water penetration problem related to water quality occurs when the rate of water movement into and through the soil is reduced by the effect of specific salts or lack of salts in the water to an extent that yield is reduced. Poor soil permeability makes it more difficult to supply the crop with water and may add to cropping difficulties through crusting of seed beds, waterlogging of surface soil and accompanying disease, salinity, weed, oxygen deficiency, and nutritional problems. The ratio of sodium to calcium and magnesium in the water, total salts, and the presence of carbonates and bicarbonates should be evaluated to determine a possible permeability problem.

3. Toxicity. A toxicity problem occurs when certain salts in the water or soil are taken up and accumulated in amounts by the plant, resulting in less vigor and yield. Boron, chloride and sodium are those frequently causing problems.

4. Miscellaneous. White deposits on the leaves or fruit due to sprinkler irrigation with water high in bicarbonates can cause reduced yields and should be evaluated. Carbonates and bicarbonates in irrigation waters can effectively reduce the calcium and magnesium to sodium ratio in the soil, causing sodium toxicities and permeability problems. High chlorides can cause leaf damage to sensitive crops when sprinkler irrigating. Excessive vegetative growth, lodging, and delayed maturity can result from the use of water high in nitrogen content.

HOW TO GO ABOUT SOLVING THESE PROBLEMS

1. Evaluate the salinity status of the soil.
2. Evaluate the quality of the irrigation water.
3. Compare these levels with those of the guidelines.
4. Determine if irrigation and/or other management practices can be altered to lower salt levels in soil or water.
5. A crop can then be chosen which will produce at an economic level under a specific set of conditions.

EVALUATION OF SOIL SALINITY STATUS AND WATER QUALITY

Water quality, as does soil salinity, depends upon many criteria. Measurements of total dissolved salts, as well as individual "good" and "bad" salts such as calcium, sodium, boron, chlorine, etc., are necessary to analyze the problem. Total salts in irrigation waters can be measured in a laboratory or in the field by use of a portable meter. Individual salt levels must be determined by more complex laboratory equipment. Soil salinity is determined from an extract of a soil sample and is not convenient for field analysis even for total salts.

Analytical procedures for laboratory determinations are discussed in USDA Handbook 60 (1954), FAO Soils Bulletin 10 (1970), and Standard Methods of American Water Works Association (1971). These, or other recognized procedures for analysis, should be followed. It is equally important to obtain representative samples to ensure the usability of the determinations made. A brief list of sampling precautions is listed in Appendix A.

What values should be checked to determine the salinity status and/or possible toxic levels of elements in soil and water? Some of the most common determinations used for analysis of a potential soils salinity or water quality problem are shown in Figure 1. Determinations of other specific elements may be necessary if suspected in amounts which may cause damage.

Figure 1.
LABORATORY DETERMINATIONS USED TO EVALUATE WATER QUALITY AND SOIL SALINITY STATUS

Laboratory Determination	Reporting* Symbol	Reporting* Units	Soil	Water	Equivalent Wt
Electrical conductivity	EC_e, EC_w	mmhos/cm, dS/m	X	X	-
Calcium	Ca	meq/l	X	X	20
Magnesium	Mg	meq/l	X	X	12.2
Sodium	Na	meq/l	X	X	23
Carbonate	CO_3	meq/l	X	X	30
Bicarbonate	HCO_3	meq/l	X	X	61
Chloride	Cl	meq/l	X	X	35.4
Sulfate	SO_4	meq/l	-	X	48
Boron	B	~~me/l or~~ ppm	X	X	-
Lime %	$CaCO_3$%	%	X	-	-
Acidity-Alkalinity	pH	pH	X	X	-
Adjusted Sodium Adsorption Ratio	adj. SAR	-	-	X	-
Gypsum Requirement	GR	tons/acre-foot	X	-	-
Exchangeable Sodium %	ESP	%	X	-	-

*Refer to glossary of terms

GUIDELINES

Guidelines provided can be used to determine a problem before planting. Chemical amendments can be applied, cultural and irrigation practices can be altered, or a change in crop can allow a crop to be produced with less chance of damage from salts.

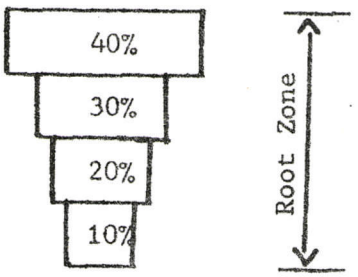
Caution! These guidelines are set up to cover a wide range of soils, crops and management practices. If your soils or management practices vary greatly from normal or average, levels may not strictly apply. Levels presented are not hard and fast rules, but serve as guidelines for management decisions. If a few basic assumptions are understood, these guidelines should be useful as a practical guide to evaluate the suitability of a water for irrigation or a soil for production of crops.

Soil and Climate. The soil texture is sandy loam to clay loam with good internal drainage. The climate is semi-arid to arid. Drainage is good without the effect of a shallow water table.

Methods and Timing of Irrigation. Surface and sprinkler methods of irrigation are assumed and water is applied on an as needed basis. With these irrigation methods, about 15 percent of the applied water is assumed to percolate below the root zone. The guidelines are believed to be too restrictive for drip or trickle irrigation and high frequency (near daily) sprinkler irrigation. These guidelines also may need to be modified for subsurface irrigation.

If less leaching is provided, salts will accumulate to a greater extent and salinity problems and yield reductions may be experienced at a lower water salinity than the guidelines indicate. If a greater leaching fraction is provided, less problems will occur than the guidelines indicate. Leaching need not be done each irrigation--only when salts near damaging levels.

Water Uptake by Crops. Water uptake by the crop takes place from wherever water is most readily available in the root zone. This is normally as shown:



Thus, the salinity of the lower root zone is considered to be of less importance as long as the crop is relatively well supplied with moisture in the upper "more active" root zone.

Degree of Problem. These divisions [no problem, increasing problem, severe problem] have proven to be practical under production agriculture conditions. Changes of 10 to 20 percent above or below the statedvalues may have little significance if considered in proper perspective with other factors affecting yield.

Specific conditions that may modify these values include the leaching fraction, drainage, tolerance to salinity of crops grown, and the chemical properties of the soil.

SALINITY PROBLEM SOLVING

Most of the salts added with the irrigation water are left behind in the soil as the water is removed by the crop. These salts accumulate in the root zone and can affect yields. To avoid salt accumulation to excess levels, they must be removed in amounts about equal to the salts applied. To accomplish this, adequate water must be applied to allow percolation through the entire root zone. This need not be done at each irrigation, but need be done only when salts have accumulated to near damaging levels. Winter rainfall or inefficiencies of irrigation may accomplish this in some cases.

If by leaching a salt balance is achieved, the average soil salinity of the root zone will be closely associated with the quality of the irrigation water and the leaching fraction.

In most situations 3 EC_w = EC_{sw}, 2 ECe = EC_{sw}, 1.5 ECw = ECe where EC_w, ECe, EC_{sw} are the electrical conductivity of the water, saturated extract of the soil, and soil water respectively.

Management alternatives for excess salinity:

- Irrigate more frequently.
- Plant crops which are tolerant of existing or potential salinity problems.
- Use extra water to satisfy the leaching fraction.
- Change method of irrigation so as to make more effective salt control.
- Change cultural practices.

For reclaiming soils or restoring productivity:

- Leach as needed to reduce salts.
- Improve uniformity of water application.
- Modify soil profile to improve percolation.
- Remove effects of water table (drainage).
- Change water supply.

Figure 2.

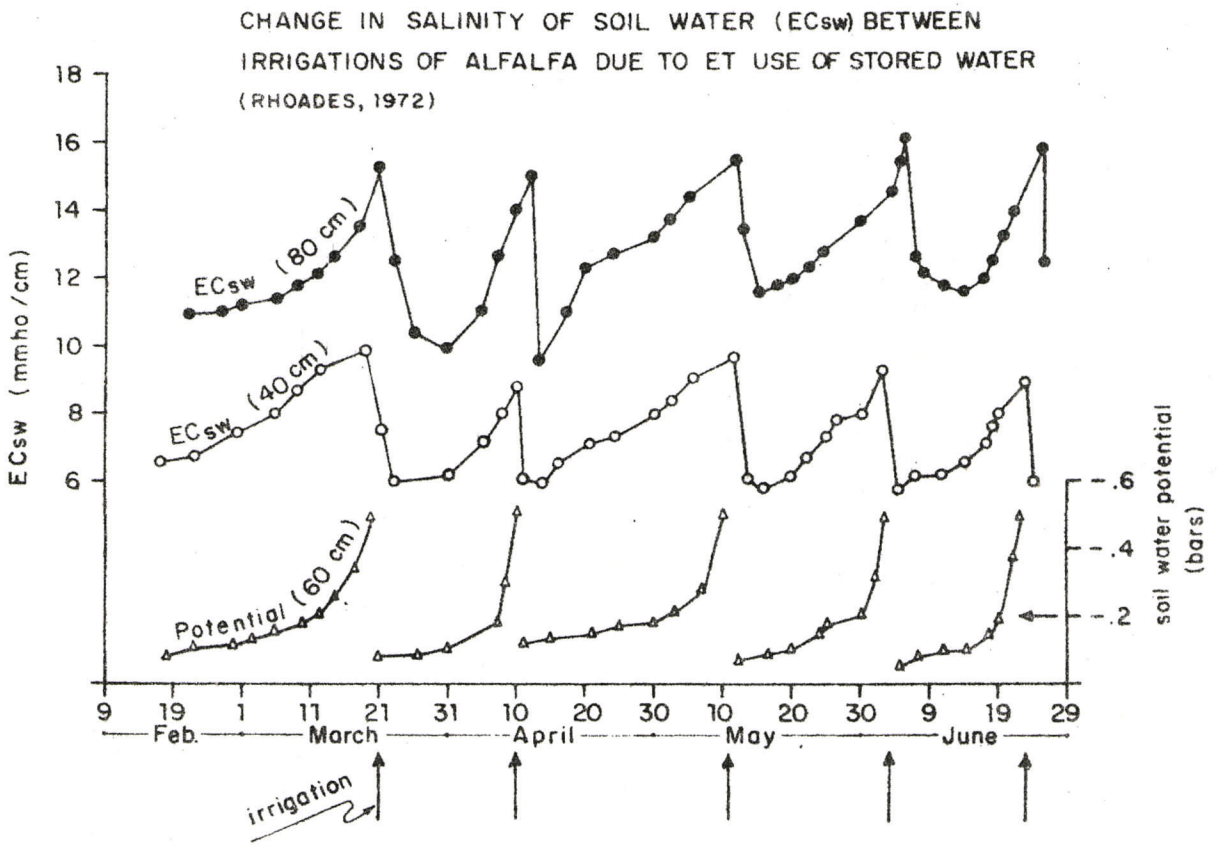

CHANGE IN SALINITY OF SOIL WATER (ECsw) BETWEEN
IRRIGATIONS OF ALFALFA DUE TO ET USE OF STORED WATER
(RHOADES, 1972)
ECsw (mmho/cm)
18
16
14
12
10
8
6
ECsw (80 cm)
ECsw (40 cm)
Potential (60 cm)
soil water potential (bars)
-.6
-.4
-.2
9 19 1 11 21 31 10 20 30 10 20 30 9 19 29
Feb. March April May June
irrigation

Figure 3.

IRRIGATION WATER QUALITY GUIDELINES

IRRIGATION PROBLEM	DEGREE OF PROBLEM		
	No Problem	Increasing Problem	Severe Problem
SALINITY (affects crop water availability)			
EC_w (mmhos/cm)	0 - 0.75	0.75 - 3.0	3.0+
PERMEABILITY (affects infiltration rate into soil)			
EC_w (mmhos/cm)	> 0.5	0.5 - 0.2	< 0.2
adj. SAR			
(expanding clays) 1/	0 - 6	6 -12 1/	12+
(non-expanding clays) 1/	0 -16	16 -24 1/	24+
SPECIFIC ION TOXICITY (affects sensitive crops)			
Root absorption			
Sodium 2/ 3/ (adj. SAR)	0 - 3	3 - 9	9+
Chloride 2/ 3/ (meq/l)	0 - 4	4 -10	10+
(mg/l)	0 -142	142-355	355+
Boron (mg/l)	0 -0.75	0.75-2.0	2.0+
Foliar absorption			
Sodium meq/l	3.0	3.0+	
mg/l	69	69+	
Chloride meq/l	3.0	3.0+	
mg/l	106	106+	
MISCELLANEOUS EFFECTS (affects susceptible crops)			
HCO_3 (meq/l) [overhead sprinkling]	0-1.5	1.5 - 8.5	8.5+
(mg/l)	90	90-520	520+
pH	[Normal Range 6.5 - 8.4]		
NH_4 } (mg/l)	0 - 5	5 - 30	30+
NO_3 }			

1/ Use the lower range if EC_w less than .4 mmhos/cm
Use the intermediate range if EC_w = 0.4 - 1.6 mmhos/cm
Use upper limit if EC_w greater than 1.6 mmhos/cm

2/ Most tree crops and woody ornamentals are sensitive to sodium and chloride (use value shown). Most annual crops are not sensitive (use the salinity tolerance tables).

3/ With sprinkler irrigation on sensitive crops, sodium or chloride in excess of 3 meq/l under certain conditions has resulted in excessive leaf absorption and crop damage.

Source: WATER QUALITY by Ayers and Branson, UC Committee of Consultants (1976)
FAO 29 (1976)

Figure 4.

SOIL SALINITY GUIDELINES

SOIL PROBLEM	DEGREE OF PROBLEM		
	No Problem	Increasing Problem	Severe Problem
SALINITY PROBLEM (affects crop water availability)			
EC_e (mmhos/cm)	[Refer to Crop Tolerance Chart EC_e]		
TOXICITY PROBLEM			
Sodium (ESP)			
General	0 - 10	10-15	15+
Sensitive crops	0 - 5	10	10+
Boron (ppm)			
Sensitive crops	0.5	1	1+
Semi-tolerant crops	0 - 5	5	5+
Tolerant crops	0 - 10	10	10+
Chloride (meq/l)			
Sensitive crops	0 - 5	5	5+
MISCELLANEOUS EFFECTS			
pH			
Range most crops		5.5-8.4	
Optimum range		6.5-7.5	

CROP TOLERANCE

All crops vary in their ability to tolerate salts. Crop tolerance is presented in these tables as if it were a fixed value. This is not exactly true. Crop tolerance changes with water management practices as well as with stage of growth, with rootstock, with varieties and climate. For many crops the germinating and early seedling stage is the most sensitive (sugar beets, rice, wheat, barley and several vegetables). Soil salinity (ECe) in excess of 4 mmhos/cm in the area of the germinating seed may delay or inhibit germination and early growth.

The tolerance values in the tables are based on the response from late seedling stage to maturity.

Soil and water salinity levels are listed under the expected yield decreases. The leaching requirement (LR) is also listed which is the minimum amount of water in percent of the total yearly water applied to experience the yield decrease at the salinities listed.

The soil salt levels (EC_e) listed in the table are rather firm as far as crop damage is concerned. If the salinity of the water (EC_w) is increased even with an increase in the leaching fraction greater than the minimum listed, the soil salinity (EC_e) will concentrate to the level indicated in the table.

CROP TOLERANCE TABLE

Yield Decrease to be Expected for Certain Crops Due to Salinity of Irrigation Water when Common Surface Irrigation Methods are Used.

FRUIT CROPS

Expected Yield Decrease	0%			10%			25%			50%			Max.
Crop	EC_e [1]	EC_w [2]	LR [9]	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e [3]
Apple, Pear	1.7	1.0	6	2.3	1.6	10	3.3	2.2	14	4.8	3.2	20	8
Walnut	1.7	1.1	7	2.3	1.6	10	3.3	2.2	14	4.8	3.2	20	8
Peach	1.7	1.1	9	2.2	1.4	11	2.9	1.9	15	4.1	2.7	21	6.5
Apricot	1.6	1.1	9	2.0	1.3	11	2.6	1.8	15	3.7	2.5	20	6
Grape	1.5	1.0	4	2.5	1.7	7	4.1	2.7	11	6.7	4.5	19	12
Almond	1.5	1.0	7	2.0	1.4	10	2.8	1.9	13	4.1	2.7	20	7
Plum	1.5	1.0	7	2.1	1.4	10	2.9	1.9	14	4.3	2.8	20	7
Strawberry	1.0	0.7	8	1.3	0.9	10	1.8	1.2	15	2.5	1.7	21	4
Fig	2.7	1.8		3.8	2.6		5.5	3.7		8.4	5.6		14
Grapefruit	1.8	1.2		2.4	1.6		3.4	2.2		4.9	3.3		8
Orange, Lemon	1.7	1.1		2.3	1.6		3.3	2.2		4.8	3.2		8

Expected Yield Decrease	0%			10%			25%			50%			
Crop	EC_e [1]	EC_w [2]	LR [9]	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e	EC_w	LR	Max. EC_e [3]
FIELD CROPS													
Barley [4]	8.0	5.3	10	10	6.7	12	13	8.7	15	18	12	29	28
Sugarbeet [5]	7.0	4.7	10	8.7	5.8	12	11	7.5	16	15	10	21	24
Wheat [4] [6]	6.0	4.0	10	7.4	4.9	12	9.5	6.4	16	13	8.7	22	20
Safflower	5.3	3.5	12	6.2	4.1	14	7.6	5.0	17	9.9	6.6	23	14.5
Soybean	5.0	3.3	17	5.5	3.7	18	6.2	4.2	21	7.5	5.0	25	10
Sorghum	4.0	2.7	7	5.1	3.4	9	7.2	4.8	13	11	7.2	20	18
Rice	3.0	20	9	3.8	2.6	11	5.1	3.4	15	7.2	4.8	21	11.5
Corn	1.7	1.1	6	2.5	1.7	9	3.8	2.5	13	5.9	3.9	20	10
Cowpea	1.3	0.9	5	2.0	1.3	8	3.1	2.1	12	4.9	3.2	19	8.5
Beans	1.0	0.7	5	1.5	1.0	8	.23	1.5	12	3.6	2.4	19	6.5
Cotton	7.7	5.1		9.6	6.4		13	8.4		17	12		27
FORAGE CROPS													
Tall wheat grass	7.5	5.0	8	9.9	6.6	10	13.3	9.0	14	19.4	13	21	31.5
Wheat grass (fairway)	7.5	5.0	11	9.0	6.0	14	11	7.4	17	15	9.8	22	22
Bermuda grass [7]	6.9	4.6	10	8.5	5.7	13	10.8	7.2	16	14.7	9.8	22	22.5
Barley (hay) [4]	6.0	4.0	10	7.4	4.9	11	9.5	6.3	16	13.0	8.7	22	20
Perennial rye grass	5.6	3.7	10	6.9	4.6	12	8.9	5.9	16	12.2	8.1	21	19
Trefoil, birdsfoot narrow leaf [8]	5.0	3.3	11	6.0	4.0	13	7.5	5.0	17	10	6.7	22	15
Harding grass	4.6	3.1	9	5.9	3.9	11	7.9	5.3	15	11.1	7.4	21	18
Tall fescue	3.9	2.6	6	5.8	3.9	8	8.6	5.7	12	13.3	8.9	19	23
Vetch	3.0	2.0	8	3.9	2.6	11	5.3	3.5	15	7.6	5.0	21	12
Sudan grass	2.8	1.9	4	5.1	3.4	7	8.6	5.7	11	14.4	9.6	18	26
Trefoil, big	2.3	1.5	10	2.8	1.9	13	3.6	2.4	16	4.9	3.3	22	7.5
Alfalfa	2.0	1.3	4	3.4	2.2	7	5.4	3.6	12	8.8	5.9	19	15.5
Orchard grass	1.5	1.0	3	3.1	2.1	6	5.5	3.7	11	9.6	6.4	18	17.5
Clover, alsike, ladino, red, strawberry	1.5	1.0	6	2.3	1.6	8	3.6	2.4	12	5.7	3.8	19	10

VEGETABLE CROPS

Expected Yield Decrease	0%			10%			25%			50%			
Crop	EC_e [1]	EC_w [2]	LR [2]	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e	EC_w	LR	Max EC_e [3]
Beets	4.0	2.7	9	5.1	3.4	11	6.8	4.5	15	9.6	6.4	21	15
Broccoli	2.8	1.9	7	3.9	2.6	10	5.5	3.7	14	8.2	5.5	20	14
Tomato	2.5	1.7	7	3.5	2.3	9	5.0	3.4	13	7.6	5.0	20	13
Cucumber	2.5	1.7	8	3.3	2.2	11	4.4	2.9	15	6.3	4.2	21	10
Cantaloup	2.2	1.5	5	3.6	2.4	7	5.7	3.8	12	9.1	6.1	19	16
Spinach	2.0	1.3	4	3.3	2.2	7	5.3	3.5	12	8.6	5.7	19	15
Cabbage	1.8	1.2	5	2.8	1.9	8	4.4	2.9	12	7.0	4.6	19	12
Potato	1.7	1.1	6	2.5	1.7	8	3.8	2.5	13	5.9	3.9	20	10
Sweet corn	1.7	1.1	6	2.5	1.7	8	3.8	2.5	13	5.9	3.9	20	10
Sweet potato	1.5	1.0	5	2.4	1.6	8	3.8	2.5	12	6.0	4.0	19	11
Pepper	1.5	1.0	6	2.2	1.5	9	3.3	2.2	13	5.1	3.4	20	9
Lettuce	1.3	0.9	5	2.1	1.4	8	3.2	2.1	12	5.2	3.4	19	9
Radish	1.2	0.8	4	2.0	1.3	7	3.1	2.1	12	5.0	3.4	19	9
Onion	1.2	0.8	5	1.8	1.2	8	2.8	1.8	12	4.3	2.9	19	8
Carrot	1.0	0.7	4	1.7	1.1	7	2.8	1.9	12	4.6	3.1	19	8
Beans	1.0	0.7	6	1.5	1.0	8	2.3	1.5	12	3.6	2.4	19	6

FOOTNOTES

1/ EC_e means electrical conductivity of the saturation extract of the soil reported in millimhos per centimeter (mmhos/cm).

2/ EC_w means electrical conductivity of the irrigation water in millimhos per centimeter. This assumes about a 15-20% leaching fraction and an average salinity of soil water (EC_{sw}) taken up by crop about three times that of the irrigation water applied (EC_w), $EC_{sw} = 3\ EC_w$. From the above, $EC_e = 3/2\ EC_w$. New crop tolerance tables for EC_w can be prepared for conditions which differ greatly from those assumed in the GUIDELINES. The following are estimated relationships between EC_e and EC_w for various leaching fractions: LF = 10% ($EC_e = 2\ EC_w$), LF = 30% ($EC_e = 1.1\ EC_w$), and LF = 40% ($EC_e = .9\ EC_w$).

3/ Maximum EC_e means the maximum electrical conductivity of the soil saturation extract that can develop due to the listed crop withdrawing soil water to meet its evapotranspiration demand. At this salinity, crop growth ceases (100% yield decrement) due to the reduction in crop water availability to zero.

4/ Barley and wheat are less tolerant during germination and seedling stage. EC_e should not exceed 4 or 5 mmhos/cm.

5/ Sensitive during germination. EC_e should not exceed 3 mmhos/cm for garden beets and sugar beets.

6/ Tolerance data may not apply to new semi-dwarf varieties of wheat.

7/ An average for Bermuda grass varieties. Suwannee and Coastal are about 20% more tolerant; Common and Greenfield are about 20% less tolerant.

8/ Broadleaf birdsfoot trefoil appears to be less tolerant than narrowleaf.

9/ Leaching requirement (LR) is the minimum amount of water as a percent of the total water requirement which is applied to leach salts out of the root zone.

Source: Data as reported by Maas, Hoffman, Bernstein (1964), and University of California Committee of Consultants (1974).

Permeability Problem Solving. Since permeability problems only reduce the volume of water placed into storage for crop use, there is little need to take corrective action until either the crop demand or leaching requirement can no longer be satisfied within the restraints of reasonable ease of management. Waterlogging, crusting, poor aeration, and excessive weeds or disease can affect the ease of management and may be as important as reductions in yield.

Management alternative or corrective action includes both chemical and physical methods --

Chemical practices:
- Use soil or water amendments (gypsum, sulfur, sulfuric acid, etc.)
- Blending or changing water supply.

Physical methods or practices:
- Irrigate more frequently.
- Cultivating or deep tillage.
- Increase duration of irrigation.
- Reduce slope.
- Recycling tailwater.
- Use organic residues.

Toxicity Problem Solving. Toxicity is a problem which results in the excessive uptake and accumulation of certain constituents from the irrigation water or soil itself. Toxic constituents of concern are sodium chloride or boron. Sprinkler irrigation practices can increase the effect of these toxic ions on crops since they are also absorbed through the leaves. Other toxic ions can cause problems and are listed in Figure 5.

Sodium. Tree crops and other woody species are particularly sensitive to low concentrations of sodium. Leaf burn or scorch, and dead tissue along the outside edge of the leaves are typical symptoms. Sodium toxicity is modified somewhat if calcium is also present. Since the effect of sodium is dependent on both the sodium and calcium, it is reasonable to use the sodium adsorption ratio for the soil and water to assess potential toxicity.

Sodium in leaf tissue in excess of 0.25 to 0.50% (dry weight basis) is typical of sodium toxicity for many tree crops. A combination of soil, water and plant tissue analyses greatly improves the chances of a correct diagnosis of the problem. Figure 3 uses the SAR to evaluate the sodium hazard of the

irrigation water to sensitive crops including fruits, nuts, citrus, avocado and beans. If soil analysis is available, the ESP can be compared to Figure 6 to give relative tolerances of representative crops. An approximate soil ESP can be obtained using the nomogram Figure 7. However, such estimates may be in error if gypsum is present in the soil.

Figure 5.

RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATERS

Element (symbol)	For Waters Used Continuously on all Soils	For Use up to 20 Years on Fine-Textured Soils of pH 6.0 to 8.5
	mg/l	mg/l
Aluminum (Al)	5.0	20.0
Arsenic (As)	0.1	2.0
Beryllium (Be)	0.1	0.5
Boron (B)	1/	2.0
Cadmium (Cd)	0.01	0.05
Chromium (Cr)	0.1	1.0
Cobalt (Co)	0.05	5.0
Copper (Cu)	0.2	5.0
Fluoride (F)	1.0	15.0
Iron (Fe)	5.0	20.0
Lead (Pb)	5.0	10.0
Lithium (Li) 2/	2.5	2.5
Manganese (Mn)	0.2	10.0
Molybdenum (Mo)	0.01	0.05 3/
Nickel (Ni)	0.2	2.0
Selenium (Se)	0.02	0.02
Vanadium (V)	0.1	1.0
Zinc (Zn)	2.0	10.0

These levels will normally not adversely affect plants or soils. No data available for Mercury (Hg), Silver (Ag), Tin (Sn), Titanium (Ti), Tungsten (W).

1/ See Figure 1.

2/ Recommended maximum concentration for irrigating citrus is 0.075 mg/l.

3/ For only acid fine-textured soils or acid soils with relatively high iron oxide.

Source: Environmental Studies Board, Nat. Acad. of Sci., Nat. Acad. of Eng. Water Quality Criteria 1972.

Figure 6.

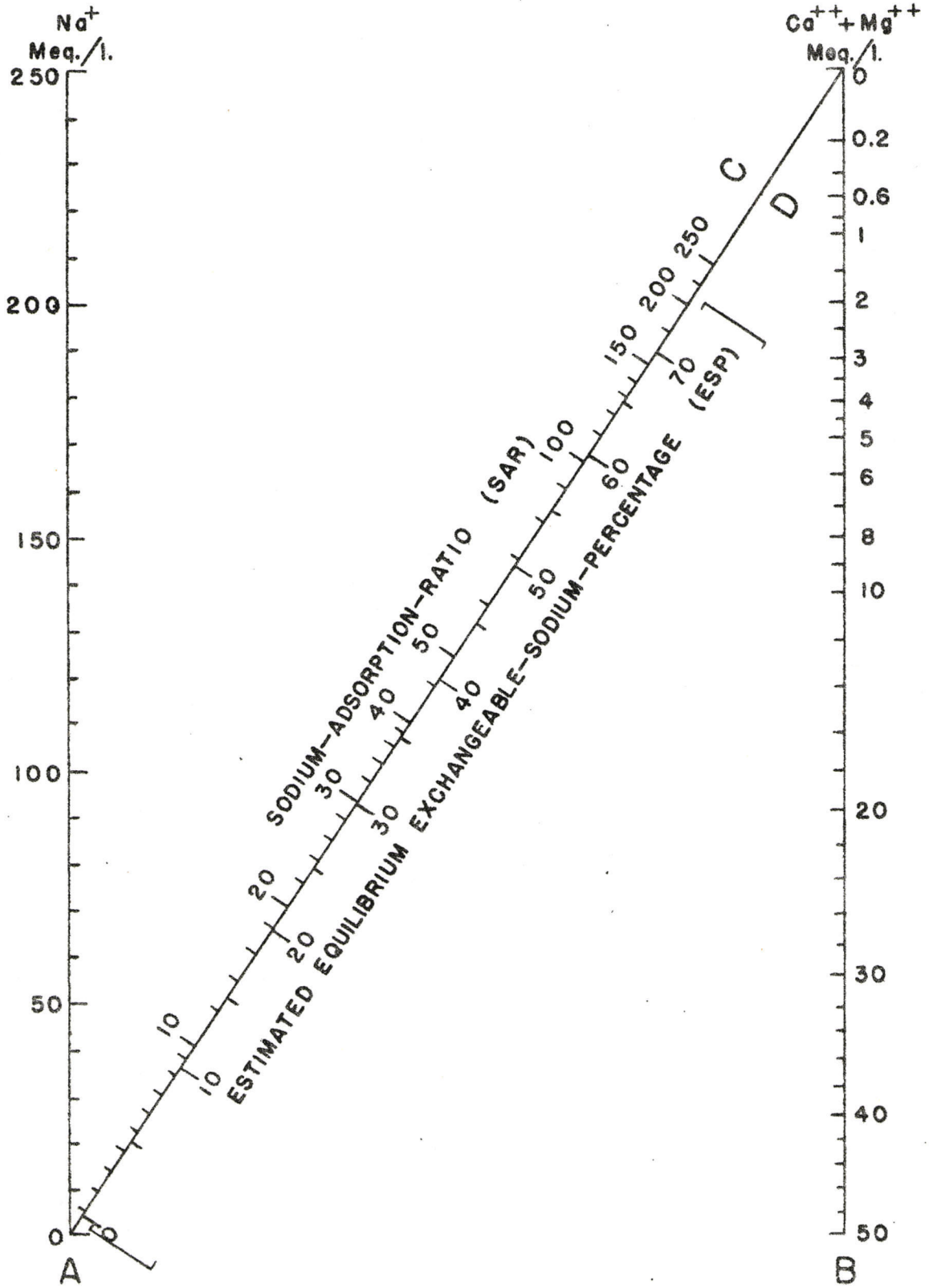
TOLERANCE OF VARIOUS CROPS TO EXCHANGEABLE SODIUM (ESP) UNDER NON-SALINE CONDITIONS (Pearson 1960)

Tolerance to ESP and range at which affected	Crop	Growth response under field conditons
Extremely sensitive (ESP = 2-10)	Deciduous fruits Nuts Citrus Avocado	Sodium toxicity symptoms even at low ESP values
Sensitive (ESP = 10-20)	Beans	Stunted growth at these ESP values even though the physical condition of the soil may be good
Moderately tolerant (ESP = 20-40)	Clover Oats Tall fescue Rice Dallisgrass	Stunted growth due to both nutritional factors and adverse soil conditions
Tolerant (ESP = 40-60)	Wheat Cotton Alfalfa Barley Tomatoes Beets	Stunted growth usually due to adverse physical conditions of soil
Most tolerant (ESP = more than 60)	Crested and Fairway wheatgrass Tall wheatgrass Rhodes grass	Stunted growth usually due to adverse physical conditions of soil

NOTE: Estimates of the ESP can be made from the irrigation water or more preferably from the SAR of the soil saturation extract. This estimation method is not applicable where soil gypsum is present. Soils at ESP = 20-40 and above will usually have poor physical structure for good crop production.

Figure 7

Nomogram for determining the SAR value of a saturation extract and for estimating the corresponding ESP value of soil at equilibrium with the extract.



To use this nomogram, add the laboratory value for Ca and Mg in meq/l and locate the sum on right vertical line of the diagram. Then locate the Na value on the left vertical line. Now lay a ruler so as to connect both located values. The SAR is then read where the ruler intersects the diagonal line. Example: Ca = 4, Mg = 2; Ca + Mg = 6. Na = 8. Then SAR = 4.8 on the diagonal line.

Chloride. Most annual crops are not sensitive to low concentrations of chloride, however, that is not the case for most tree crops and other woody perennials. Even the less sensitive crops may be affected at higher concentrations. Chloride can be taken up by crops through roots and leaves and accumulates much like sodium; however, the toxicity symptom is different. Excess chloride accumulation typically causes leaf burn at the extreme leaf tip of older leaves and progresses from the tip back along the edges as severity increases. Excessive leaf burn is often accompanied by abnormal, early leaf drop and defoliation.

Chloride content of leaves of sensitive crops in excess of 0.3 to 0.5 percent on a dry weight basis often indicates toxicity. For evaluation of chloride in the irrigation water, use Figure 3. For chloride in the saturated extract, use the chloride tolerances in Figure 8.

Figure 8.

CHLORIDE TOLERANCES IN THE SATURATION EXTRACT OF SOIL FOR FRUIT CROP ROOTSTOCKS AND VARIETIES IF LEAF INJURY IS TO BE AVOIDED (Bernstein, 1965)

Crop	Rootstock or Variety	Maximum permissible Cl in Saturation Extract
		meq/l
	Rootstocks	
Citrus	Rangpur lime, Cleopatra mandarin	25
	Rough lemon, tangelo, sour orange	15
	Sweet orange, citrange	10
Stone Fruit	Marianna	25
	Lovell, Shalil	10
	Yunnan	7
Avocado	West Indian	8
	Mexican	
Grape	Salt Creek, 1613-3	40
	Dog Ridge	30
	Varieties	
Grape	Thompson Seedless, Perlette	25
	Cardinal, Black Rose	10
Berries*	Boysenberry	10
	Olallie blackberry	10
	Indian Summer raspberry	5
Strawberry	Lassen	8
	Shasta	5

* Data available for single variety of each crop only.

Boron. Boron sensitivity exists in a wide variety of crops. It can be associated with high levels in irrigation waters, or may be caused by boron naturally occurring in the soil.

Toxicity symptoms typically show first on older leaf tips and edges as either a yellowing, spotting or drying of leaf tissue. The yellowing or spotting, in some cases, is followed by drying which progresses from the tip along the leaf edges toward the center between the veins. A gummosis also may exist on seriously affected trees.

Many sensitive crops show toxicity symptoms when boron concentrations in leaf blades exceed 250-300 ppm (dry weight). Boron does not accumulate in leaf tissue of stone and pome fruits to the extent that a leaf analysis is a reliable test. In these cases, boron problems must be confirmed from soil and water analysis, plant symptoms, and growth characteristics. Figure 9 shows crops grouped as to relative boron tolerances in sand culture.

Figure 9.

BORON IN IRRIGATION WATERS

Boron toxicity in many areas has been found to be related to use of irrigation waters with boron content in excess of 1 ppm or mg/l. The UC Cooperative Extension laboratories are using the following interpretation as regards boron content of irrigation water:

Below 0.5 mg/l	Satisfactory for all crops.
0.5 - 1.0 mg/l	Satisfactory for most crops. Sensitive crops may show injury (may show leaf injury but yield may not be affected).
1.0 - 2.0 mg/l	Satisfactory for semi-tolerant crops. Sensitive crops are usually reduced in yield and vigor.
2.0 -10.0 mg/l	Only tolerant crops produce satisfactory yields.

RELATIVE TOLERANCE OF PLANTS TO BORON[1/]

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

WATER

SENSITIVE	SEMI-TOLERANT	TOLERANT
0.5 mg/l	1.0 mg/l	2.0 mg/l
Lemon	Lima Bean	Carrot
Grapefruit	Sweet Potato	Lettuce
Avocado	Bell Pepper	Cabbage
Orange	Pumpkin	Turnip
Thornless Blackberry	Zinnia	Onion
Apricot	Oat	Broad Bean
Peach	Milo	Gladiolus
Cherry	Corn	Alfalfa
Persimmon	Wheat	Garden Beet
Kadota Fig	Barley	Mangel
Grape	Olive	Sugar Beet
Apple	Ragged Robin Rose	Palm
Pear	Field Pea	Date Palm
Plum	Radish	Asparagus
American Elm	Sweet Pea	Athel
Navy Bean	Tomato	
Jerusalem Artichoke	Cotton	
Persian (English) Walnut	Potato	
Black Walnut	Sunflower (Native)	
Pecan		
1.0 mg/l	2 mg/l	10 mg/l

From Wilcox, 1960

1/ Relative tolerance based in irrigation water at which boron toxicity symptoms were observed when plants were grown in solution culture.

MANAGEMENT ALTERNATIVES

Practices to reduce the effective concentration of toxic constituents include:

- Irrigate more frequently.
- Use additional water for leaching.
- If sodium toxic, use an amendment such as gypsum or sulfuric acid.
- Change or blend water supply.

Practices to adjust to existing conditions:

- Plant less sensitive crops.
- Use additional nitrogen to maximize growth.
- Physical changes to aid water management as listed under salinity control.
- Special techniques used when sprinkler irrigating.

MISCELLANEOUS PROBLEM SOLVING

Of primary miscellaneous concern are nitrogen, bicarbonate and pH effects.

Nitrogen. Nitrate and ammonium, if in excessive quantities in irrigation water, may delay maturity of the crop, affecting production. Production of nitrogen-sensitive crops, such as sugar beets and grapes, may be affected above 5 ppm from either nitrate or ammonium (refer to Figure 3).

Bicarbonate. Bicarbonate has been a problem primarily when fruit crops or nursery crops are sprinkler irrigated during periods of low humidity (RH <30%) and high evaporation. White deposits are formed which are not washed off by subsequent irrigation. Deposits generally reduce marketability of the fruit or nursery plants.

Toxicity is not involved, but as the salts are concentrated on the tissue, the less soluble constituents in the water (such as lime) precipitate, resulting in the white deposit.

pH. Ph can primarily be considered a good indicator for the presence or absence of other problems.

MANAGEMENT ALTERNATIVES

The management alternatives that are effective for waters high in nitrogen are:

- Plant crops not sensitive and can utilize the nitrogen.
- Blend or change water source.
- Fertilize in consideration of the water nitrogen component.

Management alternatives for correction of white deposits are:

- Irrigate at night during critical periods.
- If sprinklers rotate too slowly, increase speed of rotation.
- Do not sprinkle during periods of low humidity.
- Change irrigation method.

SYMBOLS AND ABBREVIATIONS

EC - Electrical conductivity in millimhos/cm.

EC_e - Electrical conductivity of saturated soil paste or extract.

EC_w - Electrical conductivity of irrigation water.

EC_{sw} - Electrical conductivity of soil water.

- It is possible to convert EC to ppm and vice versa; each relate the same salt level but are reported on a different scale.

EC x 640 = ppm — 1 EC = 640 ppm
ppm ÷ 640 = EC — 2 EC = 1280 ppm
1 mmho/cm = 1000 micro mho/cm
dS/m (decisiemans/meter) = mmho/cm

ESP - Exchangeable Sodium Percentage is an estimation of the degree the soil exchange complex is saturated with sodium.

GR - Gypsum requirement to improve permeability problems due to sodium. Expressed as tons of 100% gypsum per acre for 6 inch depth of soil.

LF - Leaching fraction amount of irrigation water allowed to pass through soil and out of the root zone.

LR - Leaching requirement. The minimum amount of water in percent required to leach salts out of the root zone in order to maintain a certain soil salinity.

mg/l - Milligrams of salt per liter of water or ppm.

meq/l - Milliequivalents per liter. meq/l x equivalent weight of element = ppm

- Individual salts such as sodium, calcium, chloride, etc. are commonly reported as milliequivalents per liter (meq/l). To obtain ppm of a specific salt, multiply meq/l by the equivalent weight listed in Figure 1.

Example: 10 meq/l sodium x 23 (equivalent weight) = 230 ppm sodium

10 meq/l HCO_3 x 61 = 610 ppm HCO_3

$$\frac{480 \text{ ppm } SO_4}{48} = 10 \text{ meq/l}$$

pH - Acidity less than or alkalinity greater than 7. 7 = neutral.

ppm - Parts per million. mg/l = ppm

SAR - Sodium adsorption ratio $= \dfrac{\text{Sodium}}{\sqrt{\dfrac{\text{Calcium} + \text{Magnesium}}{2}}}$

Adj. SAR - Adjusted Sodium Adsorption Ratio is a numerical relationship between calcium and magnesium to sodium in irrigation waters. The SAR value indicates a potential permeability or toxicity problem arising from the use of certain irrigation waters. Adj. indicates SAR has been adjusted by a carbonate and bicarbonate factor.

NO_3-N - Nitrate nitrogen 1 mg/l NO_3-N = 2.72 #N/Ac. ft H_2O

Appendix A.

PRECAUTIONS FOR SAMPLING

This is intended to be a very brief non-technical discussion to obtain more reliable water samples for analysis.

A laboratory analysis is no better than the sample submitted for analysis. The sample should be as representative of the conditions of use as it is reasonably possible to make it.

1. Sample bottles should be clean. If possible rinse a clean bottle, at least three times with the water to be sampled. If samples are to be analysed for boron, plastic bottles (not glass) should be used.

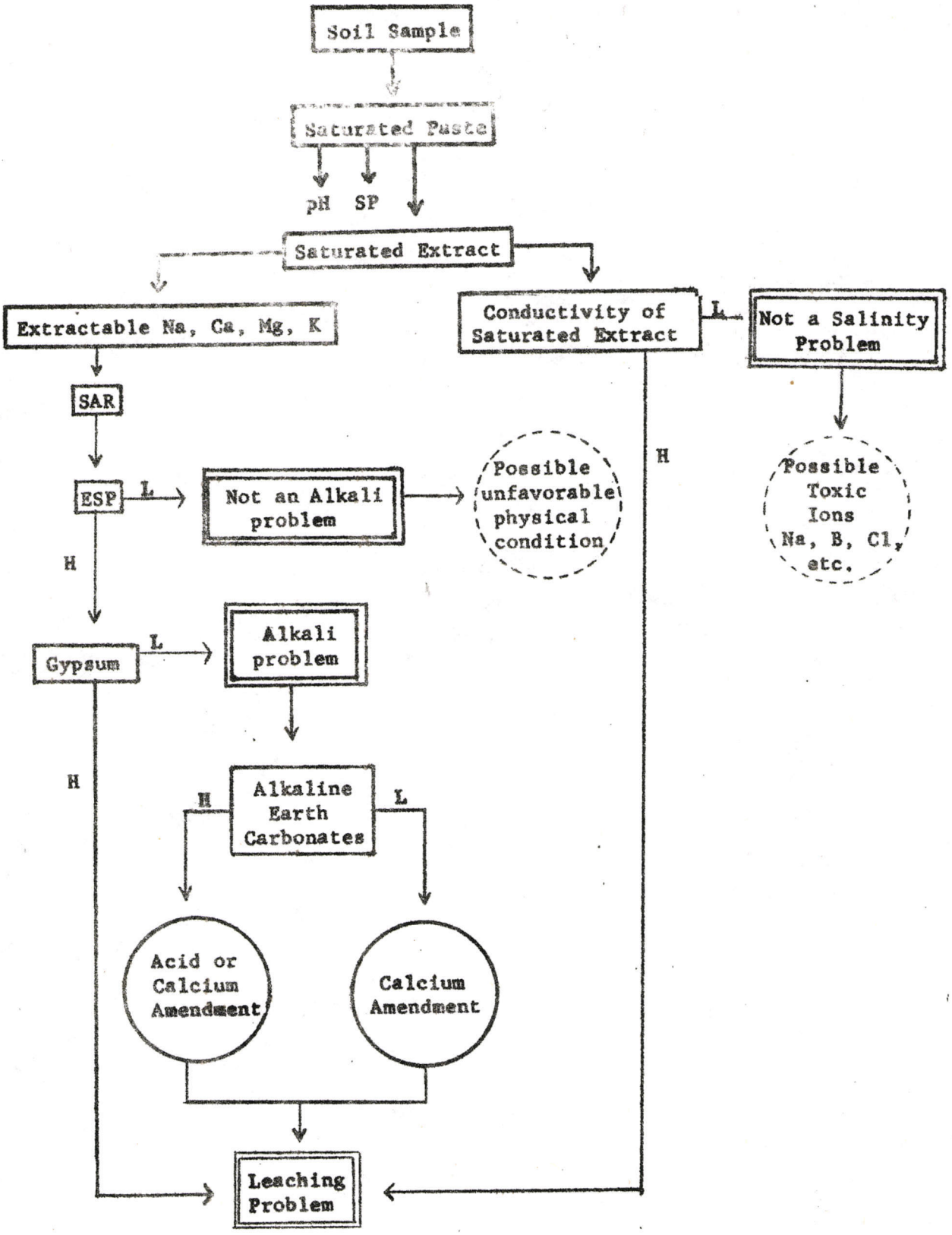
2. Size of sample: one quart or one litre is usually ample.

3. A representative sample. Take time to think about the reasons for the sample. Get a sample or series of samples that will be representative of the conditions of use. For surface waters, decide where to take the sample--surface, below the surface, near the bottom, mid-stream or edge. In taking samples representative of the water diverted for irrigation, will one sample be adequate or are differences expected in quality due to flow rate, drainage return-flow fluctuations, etc. that indicate a series of samples will be needed to show changes ? If a series is necessary, over what time interval--one day, one week, one month, one year, or several years? A choice should be made based on types and numbers of samples needed to be representative of true conditions.

For well water pumped from the underground sampling is simpler. Be sure the pump has been delivering water for at least 30 minutes. If a new well, a sample taken after surging or well development and after several hours delivery at designed capacity should be more representative than samples taken earlier.

4. Handling and storage. Samples should be kept cool until analysed. If samples cannot be analysed immediately, storage near 4°C is ideal. Samples for nitrates, ammonia or organic substances will need to be kept frozen or near freezing (4°C). This is to prevent utilization or depletion of these constituents from the sample by growth of organisms (bacteria, algae, etc.). Freezing is a very satisfactory method of holding samples prior to analysis, but remember that water expands on freezing and the container must be less than full to allow for expansion.

Appendix B.


Soil Sample
Saturated Paste
pH
SP
Saturated Extract
Extractable Na, Ca, Mg, K
SAR
ESP
L
Not an Alkali problem
Possible unfavorable physical condition
H
Gypsum
L
Alkali problem
H
H
Alkaline Earth Carbonates
L
Acid or Calcium Amendment
Calcium Amendment
Leaching Problem
Conductivity of Saturated Extract
L
Not a Salinity Problem
H
Possible Toxic Ions Na, B, Cl, etc.

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