QUALITY OF UNDERGROUND WATER FOR IRRIGATION

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Introduction

With an increasing interest in irrigation among farmers more underground water than ever before is being used for agricultural purposes. This is true in areas of relatively low rainfall as well as those of higher rainfall.

Many districts in Victoria have underground water which is generally not suitable for any type of irrigation. There are some, too, where the water quality presents few problems when used for the irrigation of almost any crop. It is those waters which fall between these two extremes which are of special interest here.

Early investigation of the quality of irrigation water tended to consider only its total content of dissolved solids. Ranges of salinities were established to represent useful water for certain types of irrigation. In one particular area such as the Mallee country in South Australia, where soil conditions do not show extreme variations and where the chemical composition of underground waters derived from the bryozoan limestone aquifer there is fairly constant, this system of establishing the suitability or otherwise of irrigation water on total salinity after many years of use has proved of value. In this case fairly saline waters have been used without serious ill-effect. However, waters with the same content of dissolved solids but of different chemical composition, when used under different conditions of drainage and soil type, may produce poor results.

It is evident, therefore, that more of the factors involved in the successful use of a particular water for irrigation should be considered if only in general terms.

A more widely applicable system of classification of irrigation waters may then be devised for use by such people as hydro-geologists, who may be connected with the utilization of underground water.

An attempt is made here to outline some of the important effects of the use of saline irrigation waters on plants and soils. It is hoped that more use may then be made of chemical analyses in determining the usefulness of a particular type of water for irrigation.

Measurement of the salinity of irrigation water

The salinity of irrigation water may be measured in several ways. The more important of these are :

a) summation of the concentrations of the principal ions determined chemically;
b) weighing the residue after evaporation of the water;
c) measurement of the electrical conductivity of the water and comparison with the conductivities of other solutions of known salinity.

For many waters of relatively low salinity the figure arrived at by evaporation is close to that arrived at by summation of the ionic concentrations.

For waters with high concentrations of bicarbonate or of such salts as magnesium chloride which remain partially hydrated in the residue after evaporation at 130°C., the content of dissolved solids determined by evaporation has been found in practice to be in serious error compared with the ionic concentration method.

Where it is possible a fairly complete chemical analysis, determining Ca, Mg, Na, Cl, SO_4, CO_3 and HCO_3 plus boron, is desirable in appraising the usefulness of water for irrigation.

The third method of determining the salinity of water, by conductivity measurement, has been widely used in U.S.A. It gives rapid results but further chemical analysis is usually necessary to determine the nature of the dissolved solids.

Effects of the use of saline irrigation water

When irrigation water is applied to the soil it has been found that the salinity of the saturation extract of the soil (i.e. the salinity of the soil solution when the soil is saturated with water) is usually from 2 to 10 or more times higher than that of the applied irrigation water. This increase in concentration of dissolved solids is due to evaporation and transpiration of water leaving any dissolved matter in the soil.

Saline soils are generally considered to be those for which the electrical conductivity of the saturation extract of the soil is greater than 4,000 micromhos/cm. at $25^{\circ}C$. This is equivalent to a salinity of the saturated soil extract of approximately 2500 parts per million (p.p.m.) Assuming the factor for increased salinity of the saturation extract of the soil over the applied irrigation water is 2, which is found to be fairly common in practice, then saline soils may result from the use of irrigation water containing about 1300 p.p.m. of dissolved solids.

If this increased salinity factor were 10 then saline soils might result from the use of water with only 250 p.p.m. of dissolved solids.

In general, waters with salinities below about 500 p.p.m. are satisfactory for irrigation so far as salinity alone is concerned. Waters having salinities in the range from 500 to 1500 p.p.m. are widely used and satisfactory crop growth is obtained under good drainage conditions etc. However, saline soils may develop if these conditions are unfavourable.

Waters with salinities greater than 1500 p.p.m. must be dealt with separately after taking into account several other factors. Under certain conditions salt-tolerant plants can be grown using irrigation water having a salinity of 3,300 p.p.m. There are reports of the use under special circumstances of water having a salinity of 6,400 p.p.m.

If water used for irrigation contains excessive quantities of dissolved solids it may effect the growth of plants in three ways, namely:

a) the increased osmotic pressure of the soil solution may decrease the physiological availability of soil moisture to the plant;

b) accumulation of certain ions in the soil solution may have a specific toxic effect upon the physiological processes of the plant;

c) adverse changes in the physical characteristics of the soil may indirectly effect the plant.

A. Effect of increased osmotic pressure of the soil solution

Experimental evidence indicates that accumulations of neutral salts in the soil inhibit plant growth primarily because of the increase in the osmotic pressure of the soil solution. This causes a decrease in the water available to the plant by way of the permeable cell walls of the roots. The osmotic pressure in atmospheres of a saturated soil extract bears a fairly close relationship to its salinity.

In most cases studied under controlled experimental conditions using different crops in saline soils, the growth reduction bears a close relationship with increasing osmotic pressure of the substrate.

For most plants there appears to be no critical level of salt concentration beyond which no growth occurs. Rather there is a progressive growth depression as salt concentration increases.

To complicate matters it has been found that some crop species which are salt-tolerant during later stages of growth may be quite salt-sensitive during germination. For example, sugar beets, which are very salt tolerant during later stages of growth, are extremely sensitive during germination. In such cases it may be possible by judicious planting to utilize rainwater during germination before having to apply saline water during irrigation of the plants in later stages of growth.

The salt tolerance of many species and varieties of crop plants has been investigated in the laboratory. The salt tolerances of the major crop divisions appear in Table I. This table was compiled by the U.S.Salinity Laboratory (1954) and is based on the relative yield of the crop on a saline

[illegible] – [illegible] soil under

soil as compared with its yield on a non-saline soil under similar growing conditions. In each crop division there are three groups of crops with high, medium and low salt tolerance respectively. Within each group the crops are listed in order of decreasing salt tolerance.

The figures for total dissolved solids in parts per million of the saturation extract of the soil are those associated with a 50 per cent decrease in crop yield.

These figures therefore represent the maximum salinity of irrigation water which could be used for the particular crops if there were no build up of the salinity of the soil solution relative to that of the irrigation water. In practice the figures for limiting salinities for irrigation water may be half or less of the maximum figure quoted in Table I for the salinities of saturated extracts of the soil.

The actual soil salinity depends on the moisture content of the soil which may be considerably less than 100 per cent. Thus the actual salinity of the soil solution may be still higher than the salinity of the saturated soil extract which is used at the standard of 100 per cent moisture content.

Thus, in using the figures for limiting salinities of irrigation water for a particular crop, the relationship of the salinity of the irrigation water to the salinity of the actual soil solution is of great importance.

B. <u>Toxic effects of specific ions</u>

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B. Toxic effects of specific ions

The injurious action of some saline waters on the physiological processes of plants is not in all cases directly proportional to the osmotic pressure of the sub-strate.

Each of the components in the saline solution may have some specific toxic effect on the plant in addition to that accounted for on the basis of the osmotic pressure of the soil solution. Such toxic effects may not always be due to direct effects on surface membranes of plant roots or in the plant tissues. Frequently toxicity may be due to the effects on the uptake or metabolism of essential nutrients.

Sodium

There is relatively little evidence to indicate the specific toxicity of the sodium ion to plants growing in saline soils. It has been found to cause tip-burn on almond leaves and leaf-burn of avocado plants.

Table I The salt-tolerance of various crops as measured by the salinity of the saturated soil extract which produces a 50 per cent decrease in crop yield.

High Salt Tolerance	Medium Salt Toler.	Low Salt Toler.
Date palm.	Pomegranate.	Pear.
	Fig.	Apple.
	Olive.	Orange.
	Grape.	Grapefruit.
	Cantaloup.	Prune.
		Plum.
		Almond.
		Apricot.
		Peach.
		Strawberry.
		Lemon.
		Avocado.

Vegetable Crops		
8000 p.p.m.	6500 p.p.m.	Equiv. to 2500 p.p.m.
Garden beets.	Tomato.	Radish.
Kale.	Broccoli.	Celery.
Asparagus.	Cabbage.	Green beans.
Spinach.	Bell pepper.	
	Cauliflower.	
	Lettuce.	
	Sweet Corn.	
	Potatoes (white rose)	
	Carrot.	
	Onion.	
	Peas.	
	Squash.	
	Cucumber.	
6500 p.p.m.	2500 p.p.m.	2000 p.p.m.

Field Crops		
10,000 p.p.m.	Equiv. to 6500 p.p.m.	Equiv. to 2500 p.p.m.
Barley (grain)	Rye (grain)	
Sugar beet.	Wheat (grain)	
Rape.	Oats (grain)	
Cotton.	Rice.	
	Sorghum (grain)	
	Corn (field)	
	Flax.	
	Sunflower.	
	Castorbeans.	

Forage Crops

12,000 p.p.m.	8000 p.p.m.	2500 p.p.m.
Alkali sacaton.	White sweetclover.	White Dutch clover.
Saltgrass.	Yellow sweetclover.	
Nuttall alkaligrass.	Perennial ryegrass.	Meadow foxtail.
Bermuda grass.	Mountain brome.	Alsike clover.
Rhodes grass.	Strawberry clover.	Red clover.
Rescue grass.	Dallis grass.	Ladino clover.
Canada wildrye.	Sudan grass.	Burnet.
Western wheatgrass.	Hubam clover.	
Barley (hay)	Alfalfa (California common) = lucerne.	
Bridsfoot trefoil.	Tall fescue.	
	Rye (hay)	
	Wheat (hay)	
	Oats (hay)	
	Orchardgrass.	
	Blue grama.	
	Meadow fescue.	
	Reed canary.	
	Big trefoil.	
	Smooth brome.	
	Tall meadow oat-grass.	
	Cicer milkvetch.	
	Sour clover.	
	Sickle milkvetch.	
8000 p.p.m.	2500 p.p.m.	1300 p.p.m.

However, the accumulation of sodium ions causes important secondary effects on plant growth through adverse changes in soil structure and the ion exchange complex of the soil. These are discussed under the heading "Adverse effects on soils as a result of the use of saline irrigation water"

Calcium

The effect of high concentrations of calcium ions in saline soil solutions upon plant growth varies with the species. It has been found during experiments on dwarf red kidney beans that the plants made less growth in $CaCl_2$ solutions than those in NaCl solutions of equivalent osmotic pressures. The difference is attributable to the more toxic effect of the Ca^{++} ion.

Magnesium

Accumulations of Mg^{++} in the substrate have been found to be toxic to plants over and above any inhibition in growth that is associated with osmotic pressure. This toxicity of magnesium may be alleviated by the presence of relatively large concentrations of calcium ions in the substrate.

Chloride and Sulphate

Many plants species are no more sensitive to chloride salts than they are to isomotic concentrations of sulphates. However, there is good evidence for specific toxicity of chloride to some tree and vine crops, including peaches and other stone fruits, citrus, avocados and grapevines, at osmotic pressures at which the sulphates are harmless. On the other hand, at equal osmotic pressures, flax and some forage plants are less affected by the presence of chlorides than of sulphates.

Bicarbonate

Heller and others (1940) studied tomatoes using water containing NaCl and $NaHCO_3$ in concentrations ranging from 100 to 3,300 p.p.m. Their results indicate that $NaHCO_3$ was more toxic than NaCl, and that it markedly inhibited the intake of Ca by plants. It has been reported that apple orchards irrigated with water relatively high in HCO_3 tend to become chlorotic. The addition of 12 equivalents per million of HCO_3 (715 p.p.m. HCO_3) to Rhodes grass had no effect whereas it caused severe chlorosis or death with Dallis grass. With beans, high concentrations of HCO_3 caused marked inhibition in growth and pronounced chlorosis.

It appears that the adverse effect of HCO_3 upon plant response is related to ionic intake and metabolism and that there may be marked differences in HCO_3 toxicity depending on the plant species.

Experiments have shown that sodium bicarbonate solutions have a more adverse effect upon the soil and the exchange complex than equivalent sodium chloride solutions. These effects will be discussed under the heading dealing with the soil changes as a result of the use of saline irrigation waters.

Boron

In addition to the elements that frequently occur in relatively high concentrations in underground water boron often occurs in low concentrations. This element is essential to the normal growth of all plants in small concentrations but is toxic if these limits are exceeded. Plant species vary both in boron requirements and in tolerance to excess boron.

The concentration of boron required for optimum growth of some plants will injure more sensitive plants. For instance, lemons show important injury when irrigated with water containing 1 p.p.m. of boron, while lucerne will make maximum growth with 1 to 2 p.p.m. of boron. The symptoms of boron injury may include burning, chlorosis and necrosis. Boron can be leached from the soil provided the initial concentration is not high.

Scofield (1936) proposed the following limits for boron in irrigation water used on crops of different boron tolerance.

Sensitive crops	1.25 p.p.m. boron
Semi-tolerant crops	2.50
Tolerant crops	3.75

Table 2 gives the relative tolerance of many plants to boron with decreasing tolerance down the lists in each group.

Tolerant	Semi-Tolerant	Sensitive
Athel	Sunflower	Pecan
Asparagus	Potato	Black walnut
Palm	Acala cotton	Persian walnut
Date palm	Pima cotton	Jerusalem artichoke
Sugar beet	Tomato	Navy bean
Mangel	Sweetpea	American elm
Garden beet	Radish	Plum
Alfalfa (lucerne)	Field pea	Pear
Gladiolus	Ragged Robin rose	Apple
Broadbean	Olive	Grape (Sultana & Malaya)
Onion	Barley	Kadota fig
Turnip	Wheat	Persimmon

Tolerant	Semi-Tolerant	Sensitive
Cabbage	Corn	Cherry
Lettuce	Milo	Peach
Carrot	Oat	Apricot
	Zinnia	Thornless blackberry
	Pumpkin	Orange
	Bell pepper	Avocado
	Sweet potato	Grapefruit
	Lima bean	Lemon

Table 2. Relative tolerance of plants to boron. (decreasing tolerance down each list). (U.S.Salinity Laboratory)

C. Adverse effects on soils as a result of the use of saline Irrigation Water.

Soils adsorb cations which are held by relatively weak chemical bonds near the particle surfaces. These ions may be replaced by others in the soil solution provided the replacing ions are more strongly held than the adsorbed ions. The reaction is known as cation exchange and is associated mainly with the clay and organic matter fractions of soils. The capacity of a soil to adsorb cations in this way is known as its cation-exchange capacity and is expressed as milliequivalents per 100 gm. of soil.

Different cations tend to be adsorbed on the same particle surface to different degrees. At a pH of 7 the degrees of adsorption for the important cations in soils are as follows: Ca > Mg > K > H > Na.

That is, with equal concentrations of these cations in solution a soil will adsorb more calcium than magnesium, more magnesium than potassium, and so on.

The cation-exchange reactions roughly follow the Law of Mass Action so that the concentrations of the cations involved will effect the equilibrium concentrations of adsorbed ions and free ions in solution. Even though the adsorption of calcium exceeds that of sodium ions from solutions of equal concentrations, this order of adsorption will be reversed if the concentration of sodium greatly exceeds that of calcium in solution.

The principal exchangeable cations found in most Australian soils are calcium and magnesium (Prescott 1952) although the relative cationic proportions may vary considerably in depth within a given soil profile. It is the accumulation of a large proportion of sodium in the exchange complex which leads to the development of alkali soils - a process which is known as alkalization. These soils develop characteristics which disturb the normal physiological processes of plants.

Characteristics of Alkali Soils

Alkali soils are generally regarded to be those which have an exchangeable sodium percentage (ESP) greater than 15. That is, adsorbed sodium ions are present in amounts greater than 15% of the total amount of exchangeable metal ions present.

Saline-alkali soils are those alkali soils for which the conductivity of the saturation extract of the soil is greater than 4000 micromhos/cm. at 25°C i.e. its content of dissolved solids is more than about 2500 p.p.m. These soils develop as a result of salinization and alkalization.

The pH of saline-alkali soils is seldom higher than 8.4 and the clay particles remain flocculated. As long as excess salts are present the appearance and physical properties of these soils are generally similar to those of saline soils.

If the excess soluble salts are removed from saline-alkali soils either naturally by rain or by the use of different irrigation methods, the exchangeable sodium begins to hydrolyze and form sodium hydroxide. As a result the pH of nonsaline-alkali soils increases rapidly and usually ranges between 8.5 and 10. The clay particles becomes dispersed and the soil becomes impermeable for the entry and movement of water and for tillage. The seriousness of this effect will depend on the ESP and clay content of the soil as well as other factors. Organic matter dissolved in the highly alkaline soil solution may be deposited on the surface by evaporation thus causing infertile dark patches to appear. This phenomenon gives rise to the term "black-alkali" soils.

In such soils it is reported that direct injury is caused to vegetation within a few inches of the surface by corrosion of the bark near the root crown. This is particularly important when sodium carbonate occurs in high concentrations in the soil solution.

The increase in pH associated with high exchangeable sodium percentages in soils causes nutritional disturbances over and above the effects of poor soil permeability and the toxicity of sodium carbonate. Plant growth on high sodium soils is inhibited by the limited availability of calcium and other essential elements (Grillot, 1954). Tolerance to high levels of exchangeable sodium seems highest in those plants which normally take in considerable amounts of sodium.

The more sensitive species are those which normally tend to exclude sodium.

The yield of tomato plants decreases as the exchangeable sodium percentage exceeds 40. The highest ESP tolerated is between 60 and 70, (Thorne, 1944). Experiments with dwarf red kidney beans at pH 6.5 have shown a marked growth decrease with an ESP as low as 15 (Bowen and Wadleigh, 1948).

There is considerable evidence that organic matter tends to counteract the unfavourable effects of exchangeable sodium on soils. The properties of soils with similar exchangeable sodium percentages vary depending on other properties such as texture, type and amount of clay minerals present, and potassium status. It is therefore difficult to define one limit beyond which it could be said the ESP is of vital importance for different soils and crops grown.

Given sufficient time the morphological features of nonsaline-alkali soils undergo significant changes. The highly dispersed sodium-saturated clay particles are easily transported downward through the soil and accumulate at lower levels - a phenomenon known as degradation. The result is that a few inches of surface soil may be relatively coarse in texture and friable. Further down, however, there will be a dense clay layer of low permeability which may develop a columnar or prismatic structure. The reclamation by leaching of saline-alkali soils therefore presents some difficulties.

<u>Sodium Adsorption Ratio</u>

In many irrigation waters sodium salts constitute a considerable proportion of the dissolved solids. It is desirable then to have some measure of the likelihood that any particular type of water will produce alkali soils when used for long-term irrigation.

The quantity which is now being used to signify this "alkali hazard" associated with the use of a particular type of irrigation water is its sodium adsorption ratio (SAR). This is computed as follows :

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

where the concentrations are expressed in equivalents per million.

This function has been found by the U.S.Salinity Laboratory (1954) to be related to the exchangeable sodium percentage in many types of soil by the equation -

$$ESP = \frac{100\ (-0.0126 + 0.01475\ SAR)}{1 + (-0.0126 + 0.01475\ SAR)}$$

From this relationship the exchangeable sodium percentage, and hence the likely degree of alkalization of a soil, may be calculated for equilibrium conditions after the use of irrigation water with a particular sodium adsorption ratio.

The nonogram in Figure 1 enables the sodium adsorption ratio and estimated exchangeable sodium percentage of a soil in equilibrium with the irrigation water to be determined from the concentrations of Na, Ca and Mg in the water. The graphs in Figure 2 provide a ready means of converting ionic concentrations in parts per million to equivalents per million.

The concentration of Na in a water sample may be calculated from a chemical analysis in which the concentrations of Ca, Mg, Cl, SO_4, CO_3 and HCO_3 are known in equivalents per million. Potassium is usually grouped with sodium and is seldom considered separately. Thus -

$$(Na)_{e.p.m.} = (Cl + SO_4 + CO_3 + HCO_3) - (Ca + Mg)$$

As has been pointed out above, the soil solution may be much more concentrated than the water applied during irrigation. Evaporation, transpiration and the possible precipitation of calcium and magnesium carbonates in the soil may greatly increase the proportion of sodium in the soil solution. Thus, the ESP in the soil may be considerably higher than that estimated from the SAR of the irrigation water.

According to the U.S.Salinity Laboratory the alkali or sodium hazard associated with the use of irrigation water having a total content of dissolved solids of 1000 p.p.m. varies in general terms with the SAR as shown in Table 3.

Sodium or Alkali Hazard	SAR
Low	<5
Medium	5 - 10
High	10 - 15
Very high	>15

Table 3. The alkali hazard using irrigation waters containing 1000 p.p.m. total dissolved solids with different sodium adsorption ratios.

It is considered that irrigation with water having a sodium adsorption ratio of say, 25, must be carried out with extreme caution.

The more saline the irrigation water the more efficient must be the drainage to prevent salt accumulation in the root zone. Since the ESP may have a direct bearing on the drainage by dispersing the clay particles, the higher the total salinity of the irrigation water the lower the SAR which can be tolerated.

An example from Victorian irrigation practice where high exchangeable sodium percentages have been of practical importance is provided in some soil horizons in the Red Cliffs irrigation district (Hubble and Crocker, 1941). In one surface horizon (Loveday sandy loam) sodium contributes 21% of the exchangeable metal ions and calcium 49%. The sodium percentage increases to 34% four feet beneath the surface. It is reported that where such high replaceable sodium contents are associated with a clay content of 20% or even less, permeability is much restricted. Drainage becomes much less efficient and salinization is difficult to prevent even with relatively low salinity irrigation water.

The Use of Waters with High Bicarbonate Concentrations

Irrigation water with a high concentration of bicarbonates may be of special importance in the formation of alkali soils and hence, indirectly at least, on the growth of plants.

Eaton (1950) has pointed out that irrigation water containing a high bicarbonate concentration may be significantly altered in the soil as a result of the precipitation of calcium and magnesium carbonates on partial evaporation. This change may greatly increase the SAR of the saturation extract of the soil since the sodium salts remain in solution.

To take this possible change into account Eaton introduced the term "percentage sodium found" which is

$\frac{Na \times 100}{Na + Ca + Mg}$ (in which concentrations of ions in the irrigation water are expressed in e.p.m.), and "percentage sodium possible" which is $\frac{Na \times 100}{Na + Ca + Mg - HCO_3}$

This gives the maximum percentage sodium in the soil solution which can result after the calcium and magnesium bicarbonates have been removed.

Such an increase in the proportion of sodium in the soil solution would not be likely to occur with irrigation waters in which chlorides and sulphates predominate in solution.

The sodium-saturated soils produced by the use of irrigation water with a high SAR may be highly impermeable and of low fertility but Eaton considers that if the irrigation water contains no sodium carbonate or bicarbonate then the occurrence of "black alkali" soils will be rare. These are soils from which organic matter has been dissolved in sodium carbonate solutions and redeposited at the surface in dark impermeable patches on which no plants will grow satisfactorily.

Breazeale (1917) states that 0.1 to 0.05 per cent of sodium carbonate renders some soils unfit for cultivation. The soil becomes cemented and barren.

If the irrigation water contains "residual sodium carbonate", that is, sodium bicarbonate or carbonate in hypothetical combination of ions in solution, then this may have a serious effect in the formation of "black-alkali" soils.

"Residual sodium carbonate" is present if the concentration in equivalents per million of calcium plus magnesium is less than the concentration of carbonate plus bicarbonate ions, i.e. $(Ca + Mg) < (CO_3 + HCO_3)$

Laboratory experiments have demonstrated that bicarbonate solutions greatly increase the ESP of the soil compared with chloride solutions of the same cationic concentrations.

With 5 e.p.m. of "residual sodium carbonate" in a solution whose total concentration was 20 e.p.m., the very high ESP of 72 resulted while a chloride solution of the same concentration and cationic composition produced an ESP of 16 (U.S.Salinity Laboratory, 1954).

On the basis of such experiments the U.S.Salinity Laboratory has tentatively drawn up the following limits for contents of "residual sodium carbonate" in irrigation waters:

"Residual sodium carbonate" in irrigation water	Usefulness
$<$1.25 e.p.m.	Probably safe
1.25 - 2.5 e.p.m.	Marginal
$>$2.5 e.p.m.	Not suitable for irrigation.

Table 4. Suggested limits for content of "residual sodium carbonate" in irrigation water.

Eaton (1950) has correlated the existence of "black-alkali" soils in Egypt with the presence of "residual sodium carbonate" in irrigation water from the Nile. The river water has an average content of 1.44 equivalents per million "residual sodium carbonate" at Cairo for 8 months of the year. The total dissolved solids amount to only about 270 parts per million. Nevertheless "black-alkali" soils frequently occur in irrigated areas.

The Tigris and Euphrates rivers have a salinity of about 50% more than the Nile but have no "residual sodium carbonate". Eaton suggests that this is the reason for the occurrence of no "black-alkali" soils in Iraq although saline soils do occur.

There appears to be a similar correlation between "residual sodium carbonate" in irrigation water and soils made useless by the occurrence of "black alkali" in the San Joachin Valley of California.

Considerable difficulty has been experienced in New South Wales and parts of Queensland where irrigation has been carried out with sodium bicarbonate waters. Impermeable and cemented layers develop, particularly on heavy soils.

The occurrence of high sodium bicarbonate waters used for irrigation in Victoria has been fairly restricted in the past. Most of the surface waters used contain no "residual sodium carbonate". However, in recent years deep drilling in the Western District and Gippsland basins has proved large volumes of soft underground water in Lower Tertiary sand aquifers. These waters contain relatively high concentrations of sodium bicarbonate but very low concentrations of calcium and magnesium as a result of cation-exchange reactions within the aquifer. Water from the Lower Tertiary sand aquifers in Portland No.2 bore has a content of dissolved solids of 1409 p.p.m. On this basis alone it is thought that restricted irrigation of the salt-tolerant plants on the better drained soils of the district would be possible. However, "residual sodium carbonate" in the water amounts to 11.4 equivalents per million and the SAR is 36.

The SAR alone is high enough to make the water of doubtful use for irrigation but the "residual sodium carbonate" content is 4½ times the maximum recommended by the U.S.Salinity Laboratory for all types of irrigation.

It is suggested therefore that while these waters may be of great value for industrial and domestic use, their continuous use for watering gardens or carrying out commercial irrigation should be regarded with caution.

Irrigation Practice with Saline Water

Most irrigation waters which have been used successfully for a considerable time have contents of dissolved solids of less than about 1500 p.p.m. The use of more saline water necessitates good drainage, leaching of the root zone and the selection of salt-tolerant crops.

Provided the physical characteristics of the soil are not likely to be greatly affected by the irrigation water, that is, the SAR and "residual sodium carbonate" content are low, the limiting factor in irrigation practice is usually the salinity of the soil solution. Since this salinity may be 10 or more times the salinity of the irrigation water, the soil salinity must be carefully observed during irrigation.

The higher the salinity of the irrigation water the greater the amount which must be applied to leach from the root zone salts which would otherwise accumulate there. The leaching requirements for particular salinities of irrigation water and maximum permissible salinities of the drainage water at the bottom of the root zone are given below :

Salinity of Irrigation Water p.p.m.	Percentage of irrigation water which must be leached through the root zone to maintain different salinities of drainage water			
	2500 ppm.	5000 ppm.	7500 ppm.	10,000 ppm.
60	2.5%	1.2%	0.8%	0.6%
150	6.2%	3.1%	2.1%	1.6%
500	18.8%	9.4%	6.2%	4.7%
1500	56.2%	28.1%	18.8%	14.1%
3200		62.5%	41.7%	31.2%

Table 5. Leaching requirements to maintain certain salinities of drainage water using saline irrigation waters.

These figures may be reduced if the rainfall makes a significant contribution towards the leaching of salts from the root zone.

The harmfulness of waters with high sodium adsorption ratios can be partially overcome by the use of additions of organic matter or calcium salts. Naturally occurring gypsiferous or calcareous soils are less liable to sodium alteration than other soils.

The method of application of the irrigation water is of considerable importance in the control of salinity.

Flooding, in which water is applied to the whole surface, is preferable for salinity control if the land is sufficiently level and the crop is of a type which can be flooded.

Furrow irrigation is useful for row crops or where the land is too steep for flooding, but salt tends to accumulate in the rows so that crop rotation may then be necessary.

Irrigation by sprinkling allows a close control of the amount and distribution of water. However, there is a tendency to apply too little water by this method and leaching of the root zone is difficult.

The higher the moisture content of saline soils the lower the actual salinity of the soil solution. Saline soils should therefore be kept at a higher moisture content than other soils by applying more irrigation water.

Conclusion

The characteristics of irrigation waters which are most important in determining their usefulness are :

a) total concentration of dissolved solids;

b) relative proportion of sodium to other cations as expressed in the sodium adsorption ratio (SAR);

c) concentration of boron or other elements which may be toxic;

d) bicarbonate concentration as related to the concentration of calcium plus magnesium.

The total dissolved solids of the water must be appraised in terms of the likely salinity of the soil solution which may be several times the salinity of the irrigation water. The salinities of the saturated soil extracts which produce a 50 per cent decrease in yield for particular crops are given in Table I. Under very good conditions of drainage, etc., it is considered that the maximum salinity of the irrigation water should not be greater than one half of the salinity of the saturated soil extract which causes a 50 per cent decrease in crop yield.

The likelihood of alkalization of the irrigated soil can be measured in general terms by the sodium adsorption ratio, but this must be considered in terms of other factors such as soil type, clay content etc.

The more saline the irrigation water the lower the sodium adsorption ratio, which can be tolerated.

Toxic concentrations of boron in underground water may not be very common although few analyses have been carried out for boron in Victoria. It is likely to occur in small amounts in most underground waters and the possibility of boron toxicity to certain sensitive plants should not be overlooked.

The occurrence of "residual sodium carbonate" in some underground waters in Lower Tertiary sand aquifers in Victoria introduces a danger of the formation of alkali soils if these waters are used for irrigation over long periods.

Special irrigation practice may be necessary when using saline irrigation water to prevent soil salinization and alkalization.

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