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Agricultural water quality criteria : irrigation aspects.

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The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Summary

Water quality criteria for irrigation are imprecise. The final result of quality evaluation depends on plant, soil and climatic variables all of which can be interdependent. A range of management strategies of varying complexity are available to mitigate the effects of poor quality water. These can be applied, usually at a cost, which will have an influence on profitability. The heavy winter rainfall in the south-west of Western Australia affects the applicability of published salinity criteria most of which have been developed in arid and semi-arid environments with little effective rainfall. Published standards are likely to be conservative under our conditions.

The need for salinity tolerance tables for crops in a Mediterranean environment and more data on response of annual crops to chloride in water are identified as research needs.

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1. Introduction

Where the available soil moisture derived from rain is deficient this lack can be made up by irrigation. To evaluate the suitability of a water supply for irrigation, information is required on quality and quantity.

The total amount of water or the rate of supply required to meet the demands of irrigated crops is often not appreciated by irrigation farmers. Yield losses from frequent or chronic shortage of water can be more serious than losses due to the salt in irrigation water.

Evaluation of water quality depends on its specific use. Experience and experimentation over the years have given rise to a set of guidelines for determining the suitability of water for irrigation.

The application of 1000 mm of water containing 1000 mgL^{-1} total dissolved solids, to a hectare of land, applies 10 t of salts. It is essential to leach this from the soil to prevent a harmful build—up of salts. As good water resources diminish, use of saltier waters will increase. Without proper management, based on knowledge of the possible harmful effects to plants and soils, prolonged use of such waters will be impossible.

2. Measuring the Quality of Irrigation Water

2.1 Electrical Conductivity

Electrical conductivity (EC) is the most convenient way of measuring water salinity. EC is determined as the reciprocal of the specific resistance (ohms.m) of the water sample corrected to a standard temperature, usually 25°C.

The basic unit of EC in SI units is Siemens m^{-1} (previously mhos m^{-1}). Formerly water salinities were expressed in micro mhos cm^{-1}. In W.A., mS m^{-1} is now the standard expression for EC of both soils and waters.

Some conversions are:

1 mS m^{-1} = 0.01 m mho cm^{-1} = 10 μmho cm^{-1}

e.g. a water may have EC = 2000 μmho cm^{-1} = 2 mmho cm^{-1} = 200 mS m^{-1}

Frequently EC is multiplied by a factor to obtain total soluble salts (mass/volume) as an expression of salinity. There is however no unique factor that can be applied and the factor will vary with composition and concentration. Factors found for W.A. waters vary between 5.0 and 8.5 (EC in mS m^{-1}). Generally it is more convenient to use electrical conductivity as the measure of salt content as criteria are usually published in this form.

2.2 Ionic Composition

Individual ions that make up the solute in water are often determined to identify specific ion toxicities and to assess the effect that the water will have on soil physical condition. The latter effect is most often assessed by the sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) of the water.

The SAR is used to estimate the sodicity hazard of the water, where:

$$SAR = \frac{Na}{\sqrt{0.5(ca + mg)}}$$ and all concentrations are in me L^{-1}

SAR is a measure of the tendency of the irrigation water to cause the replacement of calcium (Ca) ions attached to the soil clay minerals with sodium ions (Na). Sodium clays have poor structure and develop permeability problems.

The RSC is the measure in milliequivalents per litre (me L^{-1}) of the excess of carbonates ($C0_3$) and bicarbonates (HCO_3) over magnesium (Mg) and Ca. With high RSC (>1.25) there is a tendency for Ca and Mg to precipitate in the soil, thus increasing the proportion of Na and increasing the SAR of the soil solution.

3. Effects of Poor Quality Water

Both soil and plant problems can occur due to poor quality waters.

3.1 Plant Factors

3.1.1 Salinity

High soil salinity reduces the availability of soil water to the plant and induces a drought condition. This is called the osmotic effect. The severity of the osmotic effect may vary with the plants growth stage and in some cases may go unnoticed because of a uniform yield decline over the whole crop. Symptoms such as tip or marginal burn, necrosis, and defoliation may or may not occur.

3.1.2 Toxicity

Specific ions from the irrigation water may accumulate in the plant and reduce yields. Concentration by evaporation of either water droplets on foliage or of soil water may help induce specific ion toxicities.

Specific ion toxicities are commonly associated with woody perennials, such as citrus, stone and other fruits and result mainly from high concentrations of Na and chloride (Cl) ions or occasionally boron.

3.1.3 Miscellaneous

Constituents such as iron and carbonate can at high levels stain plants to cause mainly cosmetic problems.

3.2 Soil Factors

3.2.1 Permeability

When low salinity water is used on soils with high exchangeable sodium percentage (ESP) levels the soil disperses and becomes impermeable. As a result it is difficult to supply enough water to the plant. Related cultural problems include increased soil strength, crusting of seed beds, waterlogging and accompanying problems (disease, weeds, nutrition, etc.).

4. Water Quality Guidelines

Water quality criteria can never be absolute because soils, management and drainage can influence water suitability. There is, for example a ten—fold range in the salt—tolerance of plants which gives wide scope for utilising water of different quality.

Table 1 (from Ayers & Westcott, 1976) gives broad guidelines that they have developed for the preliminary evaluation of irrigation water quality. Where a water quality parameter is in the range of increasing problems more detailed investigation is required. For instance, in the range of increasing salinity problems (75 to 300 mS m^{-1}) increasing care is required in the selection of plant species and precautions are needed to minimise salt damage.

Where limitations are given the application of appropriate management methods may mean that the waters are still viable. The table thus avoids rigid classification methods which can at times be misleading.

4.1 Guideline Assumptions

The reader is referred to Ayers & Westcott (1976) for the full guideline assumptions but briefly the guidelines are for:

4.1.1 Well—drained (no shallow water table) sandy loam to clay loam textured soils. The surface layers, where the main water uptake occurs, are maintained by irrigation at a relatively low salinity with the salinity increasing with depth.

4.1.2 A semi—arid to arid climate where effective rainfall is low. Some adjustment is therefore needed for a Mediterranean climate where rainfall is high during part of the year. The guidelines in Table I are thus probably conservative for conditions in the south—west of Western Australia.

4.1.3 Surface and sprinkler irrigation methods are assumed with a leaching fraction (LF) of about 15%. LF is the proportion of water, applied in excess of crop needs, available to leach salts from the soil.

Periodic irrigation with alternate wetting and drying of the rootzone is assumed. The guidelines are thus too restrictive for trickle irrigation.

4.1.4 Other cultural inputs are adequate so that potential plant growth is possible.

5. Evaluating Irrigation Water

Figure 1 is a flow diagram suggesting a concept for assessing water quality. Water analysis and the guidelines in Table I are the tools used in the initial assessment of the water. Then management becomes a key factor in bringing both plant and soil factors together before the final decision on its suitability is possible.

Under PLANT FACTORS for example, plant tolerance allows a wide range of options as to suitable crops and this feeds back into management aspects which determine whether these crops are profitable or whether the yield losses due to salinity or toxicity are acceptable. Maas and Hoffman (1977) have extensively reviewed crop tolerance and present the yield potential as a function of soil salinity so that the expected yield loss as salinity increases can be determined. Ayres and Westcott (1976) calculate soil salinity from water salinity to enable relating of crop tolerance data, such as that of Maas and Hoffman (1977), to water salinity. The crop tolerance tables also enable consideration of a range of LF's to held avoid salinity problems but these must be related back to soil and drainage conditions and to the quantity of water available.

FIGURE 1 - Flow diagram for evaluation of water quality

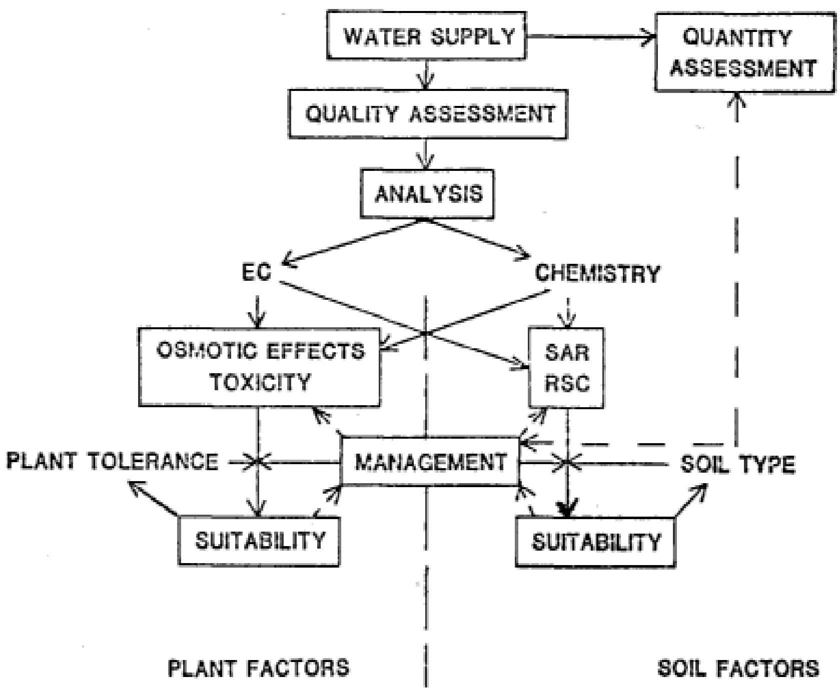

TABLE I

Guidelines for Interpretation of Water Quality for Irrigation

(Ayres and Westcott, 1976)

	DEGREE OF PROBLEM		
IRRIGATION PROBLEM	No Problem	Increasing Problem	Severe Problem
SALINITY (affects crop water availability)			
EC_w ($mS\ m^{-1}$)	<75	75-300	>300
PERMEABILITY (affects infiltration rate into soil)			
EC_w ($mS\ m^{-1}$)	>50	50-20	<20
adj. SAR [1/2/]			
Montmorillonite (2:1 crystal lattice)	<6	6-9[3/]	>9
Illite—Vermiculite (2:1 crystal lattice)	<8	8-16[3/]	>16
Kaolinite—sesquioxides (1:1 crystal lattice)	<16	16/24[3/]	>24
SPECIFIC ION TOXICITY (affects sensitive crops)			
Sodium [4/5/] (adj. SAR)	<3	3-9	>9
Chloride [4/5/] ($me\ L^{-1}$)	<4	4-10	>10
Boron (mg/1)	<0.75	0.75-2.0	>2.0
MISCELLANEOUS EFFECTS (effects susceptible crops)			
NO_3-N (or) NH_4-N (mg/1)	<5	5-30	>30
HCO_3 ($me\ L^{-1}$) (overhead sprinkling)	<1.5	1.5-8.5	>8.5
pH	Normal Range 6.5 – 8.4		

a. adj. SAR means adjusted Sodium Adsorption Ratio and can be calculated using adj. SAR = SAR [1 + (8.4-pH_c). The pH_c relates to Ca, Mg, CO_3 and HCO_3 concentrations and readers are referred to Ayers & Westcott for further details. pH_c <8.4 indicates tendency to dissolve lime from the soil while for pH_c >8.4 the tendency is for lime to precipitate from the water applied.

b. Values presented are for the dominant type of clay mineral in the soil since structural stability varies between the various clay types. Problems are less likely to develop if water salinity is high; more likely to develop if water salinity is low.

c. Use the lower range if ECw <40 mS m^{-1};
Use the intermediate range if EC_w = 40-160 mS m^{-1}
Use upper limit if EC_w >160 mS m^{-1}.

d. Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive.

e. With sprinkler irrigation on sensitive crops, sodium or chloride in excess of 3 me L^{-1} under certain conditions has resulted in excessive leaf absorption and crop damage.

Under SOIL FACTORS, where quality is marginal, Figure 1 indicates possibilities of adding ameliorants to the soil or changing to another soil type to avoid problems. Water can also be amended with additives such as sulphuric acid and gypsum to avoid soil sodicity problems. These strategies all have a cost which must be considered by management when assessing profitability.

5.1 Examples of Assessing Water Quality

Water quality assessment and the interaction of the factors involved, as shown in Figure 1, may be best shown through the following two examples (see Table II)

These waters exhibit notable differences in salinity and composition which lead to different quality considerations.

5.1.1 Wellington Dam

Consideration of Table I indicates that EC_w is in the range of increasing problems whereas permeability effects will be negligible both from the point of view of EC_w and SAR. The relevant soil types will be of the kaolinitic type further reducing the likelihood of sodicity due to water quality. Field sampling verifies this (George, unpublished data).

TABLE II

Example Water Analyses

Milli-equivalents per litre											
Source	EC_w Ms m^{-1}	Na	Mg	Ca	C11	SO_4	CO_3	HCO_3	RSC	SAR	SAR adj.
Wellington Dam	160	9.61	4.17	1.25	14.1	0.77	-	0.24	0	5.8	5.3
Lake Argyle	22	0.63	0.58	1.0	0.25	0.09	-	1.90	0.4	2.2	3.0

The guidelines indicate that it is necessary to consult detailed tolerance tables (e.g. Ayres & Westcott, 1976; Shainberg & Oster, 1978) to determine plants which would not suffer unacceptable yield loss, say greater than 10%.

It is found that a wide range of crops can grow with this salinity water including vegetable, fruit and fodder and grains crops. Beans, avocado, strawberries, onions and carrots would, under conditions assumed by the tolerance tables, suffer yield losses above 10%.

Increasing watering frequency to maintain higher moisture availability and to increase leaching fractions above the 15% assumed in the guidelines are however options available to managers who wish to grow susceptible crops. For instance to grow beans using Wellington Dam water with a 10% yield loss will require a leaching fraction (LF) of 0.27. The nett irrigation requirement will thus be ET/I—LF or 1.4 ET, where ET is crop water requirement. If there are distribution losses these will have to be allowed for in estimating the total amount of water required. It will then be necessary to review quantities of water available and determine whether the cost of this extra water is offset by returns.

Drip irrigation is another option that managers could consider. Because the soil is kept wetter, poorer quality water can be tolerated with drip irrigation once plants have become established. The data of Ayres and Westcott (1976) suggest that with high frequency irrigation systems a LF of only 0.12 will be required for beans, to give a nett water requirement of 1.14 ET. If water is scarce or expensive, drip irrigation may be the best option.

Drainage conditions are an important factor in relation to the use of the guidelines. For example, Wellington water is used to grow clover based pastures, which the crop tolerance tables indicate will suffer a 10—15% yield loss. Experimental data (George, 1979) shows however that soil salinities during the irrigation season bear little relationship to water quality. A shallow brackish water table beneath the irrigated fields controls the salinity of the rootzone. Clover yield is measured to be the same whether fresh Stirling Dam water (EC_w.= 35 mS m^{-1}) or Wellington Dam water was used so the tolerance tables are of little use in this situation.

Specific ion toxicities due to high Na and Cl are hazards indicated by the guidelines.

The sodium level of Wellington dam water is in the range of increasing problems while the Cl level is well above the severe problem level. This raises a new range of quality limitations because most tree and berry crops are sensitive to sodium and chloride. There is some difficulty in dealing with chloride levels as a water quality criterion as little data are available. Mostly toxic soil and leaf levels are given, which are useful for diagnosis of problems, but not as useful for avoiding problems.

Avocados and grapes are very sensitive to Cl in the soil solution and according to the data of Bernstein (1980) it is unlikely that the water could be used on these crops without foliage damage and leaf and yield loss occurring. Citrus are mildly tolerant of Cl in the soil however are extremely susceptible to Cl and Na when applied to the foliage. Moreover, unlike other crops which become more salt tolerant with age, fruit crops become more sensitive after 2 or 3 years. Bernstein (1980) cites carry—over of accumulated salts in the plant sap and the reduced growth rate of older plants as the probable causes of this phenomenon.

Melons and cucumbers are examples of annual crops that are more sensitive to Na and Cl intake through the leaves than the root.

Many management options are available to reduce the effects of specific ion toxicities. Sodium toxicity can be avoided by adding Ca to the water or by dilution (as SAR is concentration dependent) to reduce the SAR. Foliage uptake will be a problem with most fruit crops so it is vital that they are not irrigated with overhead sprinklers and are protected from spray drift. The use of trickle irrigation would avoid toxicity problems with many crops.

When overhead sprinklers are used to apply Wellington water, the use of large droplet, continuous wetting sprinklers and night—time watering are advisable to reduce effects due to water concentration through the air and on the leaves. Such methods however may not be successful with plants like strawberries and avocados which are much more sensitive to Cl uptake through the roots than the leaves.

Selection of specialised rootstocks can also reduce toxicity problems. Smith (1963) demonstrated that citronelle rootstocks were much more effective in excluding chloride from the leaves of Washington navel oranges than trifoliata rootstocks. Bernstein (1980) lists data for citrus, stonefruit and grapes indicating an up to 4—fold range of soil chloride tolerance for different rootstocks. West (1978) however has shown for apple trees that periods of waterlogging will cause increased levels of Cl (and Na) in the leaves. This also occurs with pears and is likely to occur with other fruit crops. It is thus an important aspect of management to avoid waterlogging when Wellington water is used on Cl and Na susceptible crops.

5.1.2 Lake Argyle

Table II shows Lake Argyle water to be a very low salinity water and to be of significantly different composition from Wellington Dam water. The major anion is HCO_3 with both Cl and SO_4 occurring in low concentrations.

The guidelines (Table I) indicate that salinity (EC_w) and chloride levels present no plant problems. The adj. SAR of 3.0 is just in the zone of increasing problems and except possibly with very sensitive crops in association with waterlogging not likely to cause toxicity problems.

Soil permeability problems however, may arise with the use of this water. The EC_w places it close to the severe problem category while the adj. SAR of 3.0 indicates that for montmorillonite —type clay soils (which the Ord soils are) there may be no problem despite the low EC_w. While it is tempting to conclude that the water is safe, the presence of alkaline soils, and an RSC of 0.4 me L^{-1} combined with relatively high Na levels in the water, are warning signs that some additional investigation is required.

It can be calculated that as this water is concentrated due to plant water use, Ca and Mg precipitate as carbonates leaving the Na in solution. As a result a disproportionate increase in the SAR of the soil solution occurs which, combined with the low EC water can cause severe soil structural problems.

A 15-fold concentration of this water is calculated to cause the SAR to increase to 10 – a potentially hazardous level for montmorillonite soils (Table I). At this level of concentration the soil solution is still far below that which will cause salinity problems.

To avoid problems (which is preferable to trying to cure them) it may be necessary either to ensure adequate leaching to reduce concentration of the soil solution or to add amendments to the water or soil.

Van der Molen (1973) indicates that the required LR is given by $LF = EC_w/f(XEC_wEC_w)$ where f ($0 < f \leq 1$) is the leaching efficiency (Boumans, 1963) and X is the maximum desired concentration. Boumans (1963) gives values of f between 0.2 and 0.6 for heavy soils because considerable water movement occurs in preferred pathways thus avoiding salt in the bulk of the soil. Using $f = 0.4$ gives a required LF of 0.20 to prevent the development of excessive SAR in the rootzone. In this situation follow—up field survey and experimentation is required to determine values of f and whether the LF required can be achieved given the soil type.

If managing the leaching factor is not practicable, preventative amendments can be added to the water or soil to remove the RSC problem. To do this 0.4 me L^1 or Ca or sulphuric acid can be added to the water or the annual equivalent added to the soil and incorporated (sulphur would substitute for sulphuric acid in this case). Amendments will add to the cost of production and will have to be considered in a budgetary context.

6. Conclusions

6.1 Criteria for water quality for agricultural uses should not be used without regard to several interactive factors. Guidelines established by Ayres and Westcott (1976) take a better approach to water quality evaluation. A range of management options of varying complexity are available to mitigate the effects of poor quality water. Improving the overall levels of agronomic and cultural management to improve water use efficiency (Bernstein, 1974) can offset yield losses due to poor quality water and improve or maintain profitability.

6.2 Plants respond to osmotic and ion toxicity effects with a gradually declining yield as water quality deteriorates. This enables the farmer either to accept this loss or to determine whether the marginal return to the cost incurred in avoiding salinity or toxicity problems is worthwhile. Because of the wide range of species tolerance to salinity and toxicity the type of crop being grown has a large bearing on these decisions.

6.3 Occasional irrigations with poor quality water are often more beneficial than no water at all especially in a Mediterranean environment where salt build—up in the soil is prevented by heavy winter rainfall (George, unpublished data). This is an important environmental consideration for the south-west of Western Australia in the application of published water quality guidelines. Most of the guidelines available are for arid or semi—arid areas where little effective rainfall occurs. Regular leaching rains increase overall leaching fractions and because of this predicted long term soil salinity levels due to salts in water may be inappropriate (Shainberg & Oster, 1978; UNESCO, 1970; Williams, 1972). While rainfall is beneficial for salinity problems this is not the case where sodicity problems have developed. Replacement of the soil solution with fresh rain water will deflocculate the soil and exacerbate permeability problems.

6.4 While crop salinity tolerance data allow assessment of degree of yield loss given a certain quality water, the same is not possible with respect to soil physical (sodicity) problems. Here there seems to be only an all or nothing choice.

6.5 Two research needs, specifically related to W.A. conditions, emerge from this discussion. These are:

6.5.1 The response of annual crops, especially vegetables, to increasing levels of chloride and sodium in the irrigation water. These crops are frequently sprinkled with water containing C1>IO me L^1 and high levels of Cl are detected in leaves. The effects on yield are poorly defined.

6.5.2 The development of crop tolerance tables specifically for a Mediterranean environment where heavy, leaching winter rains are a feature of the climate.

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