

MANUAL TO UNDERSTAND WATER REPORTS

1. INTRODUCTION

Water is the universal supporter of all life. Without water life as we know it, is not possible. Water is also a universal solvent for making elements and nutrients available to mankind, fauna and flora. Unfortunately, water also dissolves and carries unwanted elements that are harmful to life. Even the essential elements can be present in waters in unacceptably high concentrations. The concentration and type of elements as well as the unwanted biological material determines the quality of water. The quality of a water source can vary and those dependent on rain have a seasonal cyclic pattern. Normally the quality is at its poorest just before the rainy season and improves as the salts are diluted by fresh water. In arid areas the opposite is also possible. After abnormal heavy rains the salts are leached from the layers where it accumulated over many years, into the ground water. Other sources of pollution, which are not related to rainfall or geological layers, also exist. The norms applied in the classification of water for human consumption, differ from that applied to irrigation and drinking water for animals. Only reliable analytical procedures can evaluate the quality of water sources. Discussions on the results of various tests performed on waters during the classification process will be presented in this publication. As an introduction the various classes of water for irrigation and human consumption are listed, followed by more detail on the impact of each test on plant production.

1.1 Summary of Water Classes for Irrigation

The classification of irrigation water rests on two pillars. Firstly, the total soluble salt content is divided into 4 classes ranging from C₁ to C₄. Secondly the sodium hazard is also divided into four classes and indicated by S₁ to S₄ in an increasing order of magnitude. The C-classes refer to the soluble salt concentration measured as the electrical conductivity (EC) while the S-classes refer to the sodium adsorption ratio (SAR) and is internationally accepted as a way to classify irrigation waters.

C₁S₁; C₁S₂; C₁S₃; C₁S₄
TO
C₄S₁; C₄S₂; C₄S₃; C₄S₄

Description of the applications of these classes of water.

- C₁ Water that contains very low concentrations of soluble salts and is suitable for any crop on any soil. A small volume of leaching (< 10%) is required for that water approaching the upper limit of this class (25mSm⁻¹). No decrease in production even of the most salt sensitive crops is expected. A relative production of 100% can be achieved when using this water. Even the leaves can be wetted during irrigation. No special attention is required in respect of maintaining the structure of the soil. No decrease in the infiltration rate of water, even on sodium sensitive soils, is expected but the sodium content may well be of importance (See S₂ to S₄ below).
- C₂ A water suitable for irrigation of most plants or most soils, provided some leaching (>10%) takes place and drainage is possible. A decrease in production of some salt sensitive crops is expected. A relative production of 95% is expected with most crops. The use of irrigation systems that will also wet the leaves must be limited to certain crops. No special attention is required in respect of maintaining the structure of the soil. No decrease in the infiltration rate of water is expected on most soils but the sodium content may well be of importance (See S₂ to S₄ below).
- C₃ A water containing a fair amount of salts and not suitable for irrigation on all crops or any soil. Adequate drainage is essential and a leaching requirement in excess of 15% is required. Continuous attention, to monitor and maintain soil structure, is important. A decrease in yield is inevitable but depending on local conditions, still economically viable. A relative yield of less than 90% can be expected. The application of water on the leaves during irrigation is limited to a few crops. Actions to improve the soil structure and/or water penetration may be necessary from time to time, depending on the sodium concentration.

- C₄** Due to the high salt content these waters can only be used under special conditions and the supervision of a specialist. Yield reductions are usually such that the use of this water cannot be economically justified. This water cannot be applied with systems that also wet the leaves. Actions to maintain the structure of the soil, form part of the daily management program. The concentration of sodium is of even greater importance.
- S₁** A water with a low sodium concentration and low SAR that can be applied to any crop on any soil. Using this water will not decrease the infiltration rate of even sodium sensitive soils.
- S₂** A water containing some sodium but should not impair the infiltration rate of water on most soils. However a decrease in the infiltration rate can be expected on clayey soils and should be monitored.
- S₃** Water containing high concentrations of sodium and can only be used under special conditions to limit salinity. Crusting and the infiltration rate of water need constant attention by specialists. Normally a water that can only be used for irrigation provided the total salt content is low.
- S₄** This water is not suitable for irrigation with conventional systems. To maintain the infiltration rate and prevent crusting and the destruction of the structure of the soil, requires inputs that cannot be economically justified.

When a water is therefore classified as a C₂S₂ the application thereof is thus restricted as follows:

- C₂** Indicates that the water is suitable for irrigation of most plants on most soils provided some leaching (>10%) takes place and drainage is possible. A decrease in production of salt sensitive crops can be expected. The relative production of most crops will be less than 95%. Irrigation systems that wet the leaves can only be used on certain crops. An action to maintain the infiltration rate and structure is not required.
- S₂** Indicates that a reduction in the infiltration rate is not likely on sandy soils but should be monitored on clayey soils.

- 1.2 Summary of Water Classes for Human Consumption.**
When drinking water is classified the emphasis is on the possible health hazards when consuming the water over a prolonged period.
- A class 1 water refers to the ideal concentration of the elements in the water, presenting no health hazards and is suitable for life – long consumption.
 - A class 2 water refers to the maximum permissible concentration of the elements in a source that can be safely consumed for life. However any change in rainfall or season in the catchment area can turn this into a class 3 water.
 - A class 3 water cannot be consumed for more than two days running, or more than 12 days per year.

**WATER FOR HUMAN CONSUMPTION
IS CLASSIFIED AS
CLASS 1; CLASS 2 AND CLASS 3**

- 2. SAMPLING PROCEDURES**
When taking a water sample all requirements for sampling of any other commodity are also applicable. A few specific requirements need however to be underlined, viz.:
- The sample must be representative of the water source. Thus when sampling a borehole, let the pump run and take a water sample directly from the source.
 - Do not sample water next to a dam wall or near the bank of a river. Take the sample as close to the middle as possible or at least two metres away from the wall or bank and 25 to 50 cm below the surface.
 - Wash the container thoroughly and then rinse it thrice with the same water as to be sampled. Ensure that the cap is also properly cleaned.
 - When the water is destined for microbial analyses, wash your hands with a disinfectant, rinse the washed container thrice with hot water (60 – 70°C), then thrice with the water to be sampled.
 - A 500 ml soft drink polycarbonate bottle with a screw cap (Coke or Fanta) is ideally suited.
 - Identify the sample properly by affixing a label with your name and address, telephone number and the name or number of the source written with a water resistant pen, to the bottle.
 - Keep the irrigation water samples at room temperature. Samples for E.coli testing must reach CAL within 8 hours of sampling. Despatch to CAL as soon as possible.

**RINSE THE CONTAINER THOROUGHLY
WITH THE WATER TO BE SAMPLED**

3. INTERPRETATION OF THE ANALYTICAL RESULTS.

The interpretation of the results will inevitably be influenced by the application of the water. Bicarbonates are less of a problem in waters meant for human consumption than for irrigation. The following is an explanation of the standard tests done on water samples and the impact of the results on various applications.

3.1 pH

The acid level of water is measured by the pH and is reported without any unit. The following serves as guidelines when evaluating the pH of waters.

pH REFERS TO THE DEGREE OF ACIDITY IN THE WATER

Table 3.1 The optimal pH for various application

Application	Optimal range
Irrigation of open areas	5.50 to 7.50
Irrigation of protected areas	5.50 to 7.50
Irrigation in mist cambers	5.00 to 6.50
Human consumption	6.00 to 9.00
Ruminants	5.50 to 8.30
Poultry	6.00 to 8.00

❖ pH and EC

In unpolluted water a low pH is usually accompanied by a low total dissolved salt concentration and is seldom a problem in most applications. Such waters are more corrosive than waters containing more salts. Cement based piping in particular, is corroded quickly. Low pH waters can also react with the metals of piping and with copper piping the dissolved copper will react with soap, giving a blue-greenish colour to the water. Under these conditions of a low pH and a low EC, the buffer capacity of the water is also small and a small quantity (mass) of chemicals is required to change the pH. Natural waters with a high pH and relatively high concentration of soluble salts have a larger buffer capacity and more chemicals will be required to change the pH. Water can be treated to increase or to decrease the pH (acidification). Acidification of water will be dealt with in the section “Carbonates and bicarbonates”.

❖ Pollution

When natural water has a low pH and a high EC, the condition is unnatural and indicative of some sort of pollution. A high pH is usually the result of dissolved carbonates and bicarbonates. However if the pH exceeds 8.50, hydroxides are present. Hydroxides are seldom present in natural water and their presence is also indicative of pollution.

❖ The relation between pH of the water and that of the soil.

It is important to note that applying water with a high pH to a soil will not necessarily increase the pH of that soil and *visa versa*. The result of using such water will depend on the amount of H^+ and OH^- carried by the water. That is known as the buffer capacity of water.

Waters containing low salt levels usually have a low buffer capacity, carrying low concentrations of salts that can neutralise the H^+ and OH^- ions.

Therefore smaller volumes of an acid is required to lower the pH of a water with a low salt concentration to the same extent, compared to one with the same pH but a higher salt concentration.

WATER WITH A LOW pH WILL NOT NECESSARILY DECREASE THE pH OF THE SOIL

❖ Treatments

Treatments to change the pH of water to the optimal range have to be dealt with cautiously, taking into consideration the side effects of the treatment. Applying acids will decrease the pH but depending on the type of acid the accompanying ion can cause problems. When using nitric acid, nitrates will be added to the water (which is undesirable for human consumption) and need to form part of the nitrogen fertilisation program. Sulphuric acid will add sulphur and phosphoric acid phosphates. Hydrochloric acid will add chlorides, which is undesirable for irrigation but more acceptable for human consumption. Acidifying the soil will dissolve more salts resulting in an increase in the EG of the soil solution. This could damage plants and reduce crops. Letting the water pass through a cylinder containing marble chips can raise the pH of water, especially drinking water. The size of the cylinder will be determined by the flow rate and volume of water required.

MARBLE CHIPS WILL INCREASE THE pH OF WATER

3.2 Electrical Conductivity

The electrical conductivity (EC) is an indirect measurement of the concentration of the salts dissolved in the water. It is the most used measurement in water analyses and summarises a number of quality properties. The EC alone however does not identify the types of salts present. The international unit of measurement of the EC is milli Siemen per metre ($mS\ m^{-1}$).

EC is expressed in milli Siemen per metre ($mS\ m^{-1}$)

Many other units are also being used to express the EC namely;

- milli-Siemen per centimetre (mScm^{-1}) and $1 \text{ mSm}^{-1} = 100 \text{ mScm}^{-1}$
- micro-Siemen per metre (uSm^{-1}) and $1 \text{ mSm}^{-1} = 1000 \text{ uSm}^{-1}$
- milli-mho per centimetre (mmho cm^{-1}) and $1 \text{ mSm}^{-1} = 100 \text{ mmho cm}^{-1}$ (mho and Siemen have the same value).
- micro-mho per metre (umho m^{-1}) and $1 \text{ mSm}^{-1} = 1000 \text{ umho m}^{-1}$.

$\text{mScm}^{-1} \times 100$	=	mSm^{-1}
mmho m^{-1}	=	mSm^{-1}
mmho cm^{-1}	=	mScm^{-1}
$\text{mmho cm}^{-1} \times 100$	=	mSm^{-1}
$\text{uSm}^{-1} \div 1000$	=	mSm^{-1}
$\text{uScm}^{-1} \div 10$	=	mSm^{-1}

3.2.1 EC as a Tool to Classify Water

The EC is widely used to determine the application restraints of waters because this measurement is quick, cheap and summarises a number of properties. The following serves as a guide to evaluate waters based on the EC.

Table 3.2.1 Optimal EC of water for various applications.

Application	Optimal range	Remark
Irrigation of open areas	less than 25 mSm^{-1}	No salinity hazard
	25 to 100 mSm^{-1}	Small possibility of salinity
	101 to 125 mSm^{-1}	Salinity will be a real problem
	126 to 175 mSm^{-1}	Specialist attention required
	$176+$	Salinity will render operation uneconomical
Hydroponics	less than 50 mSm^{-1}	Suitable for the most applications
	50 tot 100 mSm^{-1}	Could be used depending on the types of salts present
	$101+$	Requires the attention of a specialist
Mist cambers	less than 50 mSm^{-1}	No problems expected
	More than 50 mSm^{-1}	Depending on the pH a white precipitate will accumulate on the leaves
Human consumption	Less than 300 mSm^{-1}	Depending on the types of salts
Ruminants	Less than 300 mSm^{-1}	Depending on the types of salts
Poultry	Less than 75 mSm^{-1}	

Apart from the direct application, several other applications and decisions in plant production are based on the EC reading. The most important revolve around formulation of nutrient solutions, leaching and production goals.

3.2.2 Formulation of Nutrient Solutions.

The EC also measures the concentration of dissolved salts and therefore a relation between EC and total dissolved salts should be possible. On average the relation is $\text{EC} \times 6.4 = \text{mg salts per litre water/solution}$.

$\text{EC} \times 6.4 = \text{mg salts per litre solution}$
and visa versa

This however is only an average and a tool when formulating nutrient solutions. Deviations to this relation are caused by the activity and size of the individual ions. Table 3.2.2 shows the EC of various pure solutions.

Table 3.2.2 The influence of different ions on the EC of solutions of several pure chemicals at a concentration of 1000 mg salt per 1000 ml water.

DISSOLVED SALT	IONS	EC mSm^{-1}	pH
Ammonium Nitrate	NH_4^+ + NO_3^-	165	5.15
Ammonium Sulphate	NH_4^+ + SO_4^{--}	185	5.30
Ammonium Chloride	NH_4^+ + Cl^-	240	5.15
Mono Potassium Phosphate	K^+ + HPO_4^{--}	75	4.50
Di-Potassium Phosphate	K^+ + H_2PO_4^-	120	9.10
Potassium Nitrate	K^+ + NO_3^-	105	5.25
Potassium Sulphate	K^+ + SO_4^{--}	140	5.35
Potassium Chloride	K^+ + Cl^-	185	5.50
Calcium Nitrate	Ca^{++} + NO_3^-	120	5.25
Calcium Chloride	Ca^{++} + Cl^-	150	5.55
Magnesium Nitrate	Mg^{++} + NO_3^-	60	6.00
Magnesium Sulphate	Mg^{++} + SO_4^{--}	68	6.05
Magnesium Chloride	Mg^{++} + Cl^-	85	6.25
Sodium Nitrate	Na^+ + NO_3^-	125	5.60
Sodium Sulphate	Na^+ + SO_4^{--}	145	6.00
Sodium Chloride	Na^+ + Cl^-	185	6.25
Average EC		136	

It is therefore important, when formulating a nutrient solution to choose those salts with the lowest EC and to also incorporate the concentration of the elements already dissolved in the water. Further more, almost

all carbonates and bicarbonates should be “replaced” in the solution by acidification.

The EC of “pure” water is <0.3 mSm⁻¹

As an example the following will illustrate the incorporation of the elements in the water into the nutrient formulation.

Nutrient	Required concentration	Composition of the water		Additions
	mg/liter	me/liter	mg/liter	mg/liter
Potassium	300	0.01	0	300
Calcium	100	2.54	51	49
Magnesium	50	1.65	20	30
Sodium	0	1.82	42	0
Ammonium-N	25	0.25	5	20
Sulphate	225	1.01	97	128
Chloride	3	2.91	102	0
Carbonate	0	0	0	0
Bicarbonate	0	2.10	128	0
Nitrate-N	125	0.16	10	115
Phosphate	50	0	0	50

Firstly the 2.10 me bicarbonate is displaced by 60 ml phosphoric acid or 155 ml nitric acid per 1000 litres water (see table 9.2). That will add 15 mg P or 27 mg NO₃-N per litre water. Secondly the rest of the additions are selected to give the lowest EC. Cost of the chemicals is also important and when a particular crop can for instance tolerate more chlorides, the cheaper chloride source can be selected.

Process of formulating a nutrient solution

1. Displace the bicarbonates
2. Incorporate the elements in the water
3. Select the salts with the lowest EC

3.2.3 Leaching Requirement

Another application of the EC of water is in the calculation of the leaching requirement (LR) for a crop irrigated with this particular water. The LR is the additional volume of irrigation water that needs to be applied, after field water capacity (FWC) (or container capacity in nurseries) has been reached, to keep the concentration of salts in the root zone, constant.

Leaching requirement is the additional volume of irrigation water to be applied

The LR is therefore an important concept wherever irrigation is practised, and is a factor of the EC of the water, the crop and the type of the soil involved. The LR is calculated by $LR = EC_w \div 5 \times EC_s - EC_w$ where EC_w is the EC of the irrigation water and EC_s the maximum EC of the saturated soil paste where no decrease in yield is evident. EC_s will differ slightly from soil to soil but the following EC_s can be used to calculate the LR (Table 3.2.3)

$$LR = EC_w \div 5 \times EC_s - EC_w$$

Table 3.2.3 Maximum EC of the saturated soil paste (EC_s) where no decrease in yield is experienced.

Crop	EC_s
Almond	185
Apple	200
Apricot	190
Asparagus	600
Avocado	125
Barley	600
Beetroot	425 but more sensitive during germination.
Broccoli	400
Cabbage	200
Carrot	100
Cauliflower	500
Celery	175
Citrus	200
Clover	175
Cotton	750
Cucumber	225
Dates	600
Dry beans	120
Fig	370
Grapes	300
Green beans	100
Green pepper	175
Lettuce	125
Lucerne	250
Macadamia nuts	150
Maize	175
Mango	125
Melon	175
Oats	425
Olive	380
Onion	125
Peach	210
Peanut	300
Pear	200
Peas	125

Pecan nut	175
Potato	195
Pumpkin	300 tot 450
Radish	110
Strawberry	110
Sorghum	425
Soybean	450
Spinach	250
Sugar cane	225
Sunflower	525
Sweet corn	170
Sweet potato	150
Tomato	220
Turnip	90
Walnuts	170
Watermelon	250
Wheat	550 but more sensitive during germination.

a LR of 20% means that an extra 20% water needs to be applied after FWC or CC has been reached.

A LR of 20% means that extra 20% water needs to be applied after FWC or CC has been reached to ensure that the salts left behind after the last irrigation being leached beyond the root zone. If an application of say 30 mm was required to rewet the soil to FWC, then 36 mm must be applied to cater for the LR. If leaching is inadequate salts will accumulate in the root zone causing the EC to increase and the plants need increasing amounts of energy to absorb the water. A condition known as “physiological drought” develops and systematically decreases production. In the advanced stage of salinity plants will die back and crops will fail completely. An important principle is to maintain an even EC level in the root zone. Therefore leaching every now and then is not a desirable practice. With every irrigation some “extra” water, the LR, must be applied.

It is undesirable to leach every now and then.

It is also important to note that the EC in the root zone will be at the lowest level just after irrigation and at it’s highest just before irrigation. After irrigation plants will utilise the water and water will evaporate from the surface, and the salt concentration will gradually increase. Water with a high EC can better be utilised through drip or pulsating irrigation systems where multiple applications per day are possible without risking over irrigation. By doing that the EC can be kept constant. Even at a fairly high level, thus enabling the plants to adapt to such adverse conditions.

Keep the EC in the root zone constant

The development of salinity in the absence of adequate leaching can be demonstrated as follows:

When 1000 ml water with an EC of 125 mSm⁻¹ is applied to a soil, about 800 mg salts (125 x 6,4) are added to the soil. Plants will utilise some of the salts, but say 400 mg remains in the soil. When another 1000 ml of this water is poured onto the soil and no leaching occurs, the remaining salts will now increase to 800 mg. Leaching is therefore required to keep the remaining salt in the soil to a level equal to that of one. Those left behind by the previous application, should be removed from the root zone (leached) by the following application. The volume of water required to do that is the LR for that water/nutrient solution and crop.

3.2.4 Osmotic Potential

The osmotic potential (OP) of the soil solution (the water adsorb and absorb by the soil particles) is a function of the salt concentration and thus the EC. A direct logarithmic relation between EC and OP exists. Many plants can utilise water very easily if the OP is less than 50kPa. Above 50kPa plants need extra energy for this function. At an OP of 50 kPa the EC will be 150 mSm⁻¹. Therefore at an EC above 150 mSm⁻¹ plants will sacrifice other functions like dry matter accumulation and hence fruit size and quality to get hold of the water. To illustrate this, the accumulated dry matter of the roots, shoot growth, stem diameter, leaf surface area and length of the feeder roots of citrus were reduced by 60% when the OP was increased from 50 to 100 kPa. As with EC, plants subjected to the least fluctuations in OP will yield best in terms of total yield and quality.

At an EC of 150 mSm⁻¹ the OP will be 50 kPa

3.2.5 Electrical Conductivity and Plant Production.

The values quoted in table 3.2.3 are the maximum permissible EC and are only applicable to open ground systems and are higher than those for hydroponics and semi-hydroponics systems. In soils the EC is “experienced” in a colloidal system in the presence of clay and humic particles, where other forces are operating. However there is a generalised relation between the EC of the water or nutrient solution and that of the soil solution or growth medium. The relation can be quantified as EC of the water or nutrient solution x 1.50 = EC of the soil or growth medium solution.

EC water or nutrient solution x 1.50 = EC of the soil or growth medium solution.

Using the EC value of 110 mSm^{-1} (in table 3.2.3 above) for strawberries, the EC of the irrigation water or nutrient solution should not exceed $110 \div 1.50 = 73 \text{ mSm}^{-1}$ for a 100% relative yield.

The optimal EC of the water or nutrient solution is given at 25°C . If the temperature of the water deviates, adjustments in the optimal EC are called for. For any 1°C deviation above 25°C the optimal EC must be reduced by 2%. For any 1°C below 25°C the optimal EC must be increased by 2%. These adjustments will also keep the OP constant. Thus, if the optimal EC for a crop is 125 mSm^{-1} at 25°C then the optimal EC at 15°C will be 150 mSm^{-1} and $112,5 \text{ mSm}^{-1}$ at 30°C . When the temperature increases the EC must be adjusted down and when the temperature decreases the EC must be increased. Adjustments in the EC therefore need to be done during winter, spring, summer and autumn and in very intensive cultivation systems, even during day and night. Production systems providing for such adjustments deliver noticeably better yields and quality.

For any 1°C above 25°C the EC must be reduced by 2%.
For any 1°C below 25°C the EC must be increased by 2%.

4. TOTAL DISSOLVED AND TOTAL SUSPENDED SOLIDS.

Waters carry dissolved salts, which will precipitate on evaporation and remain in the container. This can be measured as total dissolved solids (TDS) and is expressed in mg per litre water. Water can also carry solids that will not dissolve and these are referred to as total suspended solids (TSS) and are also expressed in mg per litre water. In some applications measuring the TDS and TSS are important.

5. POTASSIUM (K), CALCIUM (Ca), MAGNESIUM (Mg) AND SODIUM (Na).

The cations predominantly present in natural waters are sodium, calcium, and magnesium and to a lesser extent potassium. Due to pollution, ammonium (NH_4) is currently present in much higher concentration than a couple of years ago and will be dealt with at a later stage.

The concentrations of these cations are reported mainly in me or mg per litre water and the relations are as follows;

Potassium (K) me K $\times 39.10 = \text{mg K per/l water}$
Calcium (Ca) me Ca $\times 20.04 = \text{mg Ca per/l water}$
Magnesium (Mg) me Mg $\times 12.15 = \text{mg Mg per/l water}$
Sodium (Na) me Na $\times 22.99 = \text{mg Na per/l water}$

The concentration of K in natural water is usually very low and bears no relevance on the classification of water.

When the concentration reaches significant levels, it usually indicates some sort of pollution. The concentrations of the other three-cation are used to classify waters and their actual concentrations and mutual relations are important. This cation therefore has an individual and a combined influence on the quality of waters.

5.1 The Individual Influence of Calcium
Calcium is considered to be the “good” cation in water and soil. When adequate calcium is present less problems with water penetration, crusting and soil structure are experienced. In waters containing high concentrations of calcium, a high pH can result in precipitation of the calcium carbonate in pipes, emitters and on leaves. When calcium is precipitated like that, the concentration of Ca in the water decreases and the relative concentration of sodium to Ca increases, resulting in an elevated sodium hazard. However if the pH of such waters can be reduced, the calcium will stay in solution and will contribute positively to the calcium nutrition of the plants. At a pH of about 6.00 all the calcium should stay in solution. When formulating a nutrient solution, the calcium content of the water should thus form part of the total requirement provided the pH is not too high.

Calcium is the “good” cation in water and soil.

5.2 The Individual Influence of Magnesium.
Magnesium is also considered to be a “good” cation but only up to the point where it starts to interfere with the uptake of potassium by plants. Under certain conditions, magnesium will compliment the influence of sodium in respect of soil crusting and water penetration and calculating the $\text{Na}+\text{Mg}$ adsorption ratio in addition to the SAR, might supply useful information. Magnesium will also precipitate as carbonate at high pH levels and acidification will keep it in solution. Like calcium, the magnesium content of the water should be incorporated into the formulation of a nutrient solution. If this is not done, too high magnesium levels in the nutrient solution will suppress the uptake of potassium and might lead to K deficiencies.

Magnesium can compliment sodium in respect of soil crusting and water penetration

5.3 Hardness of water
Hardness of water refers to it's ability to foam when soap is added, and the formation of precipitates and scale on heating elements and equipment but also poses health hazards (see table 11.10).

Hardness is based on the Ca and Mg concentrations and is expressed as the mg CaCO₃ per litre water. The calculation is as follows;

me Ca per litre x 0.01 = mg Ca per litre
 me Mg per litre x12.15 = mg Mg per litre
 me Ca per litre x 2.497 = mg CaCO₃ per litre.....a
 me Mg per litre x4.116 = mg CaCO₃ per litre.....b
 a + b =Total hardness in mg CaCO₃ per litre

Interpretation of the results is as follows (Table 5.1)

Table 5.1 International classification of hardness of water

Range mg CaCO ₃ per litre	Description of the hardness
0 to 50	Soft water
51 to 100	Reasonably soft water
101 to 150	Slightly hard water
151 to 200	Reasonably hard water
201 to 300	Hard water
> 300	Very hard water

The concentrations of Al, Fe, Zn, Mn and Sr are usually so low that they can be ignored. However, if present in significant concentration, should be added to the calculation of total hardness. These elements can also cause hardness.

Hardness is the inability to foam and the tendency to precipitate on heating or evaporation

5.4 Individual Influence of Sodium.

Sodium is an essential nutrient element for plants, but due to the abundance of sodium in waters and soil, it is more often a matter of too much than too little. Sodium salts are very soluble in water and will not precipitate as easily as Ca and Mg salts. Even at high pH levels, the sulphates and carbonates of sodium will not precipitate like the calcium salts and magnesium carbonate. The relative concentration of sodium to Ca and Mg will then increase causing problems in the soil. Unlike calcium, sodium is regarded as the “bad” cation. Sodium as such, has a much smaller negative effect on plant growth than the same concentration of for instance chloride. Trials with sodium nitrate gave results comparable to calcium nitrate. The problems caused by excessive sodium are related to the negative effects of Na on the physical conditions of the soil. This condition is described as the SODIUM HAZARD and constitutes two components viz. the current SAR (see below) of the water when analysed with all the Ca and Mg still in solution and the situation that will developed when some of the Ca and Mg are precipitated due to the carbonates. The latter is known as the residual sodium bicarbonate (RSB see below).

Sodium has a much smaller negative effect on plant growth than chloride

Sodium has a deteriorating effect on the physical properties of the soil

5.4.1 The Sodium Adsorption Ratio.

The sodium adsorption ratio (SAR) describes the mutual relation between Ca, Mg and Na on an equivalent basis and is calculated as follows;

$$SAR = \frac{\text{Concentration Na in the water (me per litre)}}{[\text{Concentration Ca}^{+2} + \text{Mg}^{+2} \text{ in me per litre}]^{+2}}$$

Waters with an SAR <1.00 pose no problems and the sodium hazard is negligible. Waters with SAR values between 1.00 and 3.00 are potentially sodium hazardous. Precautions to prevent accumulation of sodium and deterioration of the physical properties must be put in place. A decrease in the infiltration rate of the soil is the first symptom of deterioration showing ponding and/or run off. The higher the clay content the more sensitive the structure to a high SAR. Waters with SAR values in excess of 3.00 can only be used under specialist supervision, monitoring the water management and soil structure. The “gypsum test” is convenient to measure the magnitude of the sodium hazard.

SAR < 1.00 gives no problems
 SAR of 1.00 to 3.00 has a potential for problems
 SAR > 3.00 requires special attention

5.4.2 Gypsum Test

The gypsum test is a quick and convenient method to estimate the need to apply gypsum to a soil or the accumulation of sodium in a soil. The following procedure can be applied in the field.

- Collect a soil sample of the effected soil and split it into two parts of about 250 ml each. If crusting is suspected, sample only the top 10 mm soil layer.
- Put each portion in a “funnel”. The funnel can be homemade by using the tapered end of a two-litre soft drink bottle. Plug the neck with cotton wool or cotton waste.
- Split a sample of the irrigation water into 2 parts of about 500 ml each. Add a handful of gypsum to one part and stir. Let the undissolved gypsum settle.
- Pour the gypsum water into one funnel containing the soil and irrigation water without gypsum into the other funnel.

- Note the infiltration rate and the clearness of the water filtering through the soil.
- If the soil treated with gypsum water filters quicker and clearer than the soil without gypsum, then this soil requires a gypsum application.
- Repeat the test a year or so later to monitor salination of the soil by comparing filtration rates and clearness on a year-to-year basis.

5.4.3 Residual Sodium Bicarbonate (RSB)
 The RSB describes the conditions in the water after all the carbonates have precipitated as Ca and Mg carbonates and refers to the worst scenario in respect of the SAR of such a water.

The RSB estimates the worst scenario of the SAR

The RSB can be calculated by deducting the me Ca + Mg from the me CO₃ + HCO₃ and compared with the values in the next table.

RSB	Quality of the water
0 to 1.25	Good
1.26 to 2.50	Fair
2.51 +	Poor

6. AMMONIUM AND NITRATE NITROGEN
 These two are the most important forms of inorganic nitrogen present in natural waters. The concentrations are reported in mg NO₃, NO₃-N, NH₄ and NH₄-N per litre water.

One mg NO₃-N = 4.4286 mg NO₃ and one mg NH₄-N = 1.2857 mg NH₄.

1 mg NO₃-N = 4.4286 mg NO₃
 1 mg NH₄-N = 1.2857 mg NH₄.

Irrigating with waters containing significant levels of these two ions could cause problems on crops where the nitrogen application is restricted to certain phenological stages. Most fruit production programmes exclude nitrogen application during the maturing phase. If the irrigation water contains high levels of nitrogen then this (no nitrogen applications) cannot be practised.

Quality of fruit is the first to suffer. Depending on the concentration, the presence of nitrogen in water, threatens the very existence of agriculture. The source of the ammonium and nitrate ions is primarily leaching of nitrogen from fertilised sites. Over-fertilisation with, and excessive leaching of nitrogen, threaten the very same industry. In table 6.1 the concentration of nitrate and ammonium nitrogen of water is put into perspective by linking concentration to application of water and nitrogen (kg N per ha).

Table 6.1 Nitrogen applications in kg N per ha in relation to the concentration in the water at precipitation rates of 200 to 1000 mm per season.

Concentration NH ₄ -N + NO ₃ -N mg per litre water	mm irrigation per season					
	200	400	600	800	1000	
10	20	40	60	80	100	
15	30	60	90	120	150	
20	40	80	120	160	200	
25	50	100	150	200	250	
30	60	120	180	240	300	

Irrigating fruit trees the following masses of nitrogen (table 6.2) will be applied per tree per day where the water requirement varies from 20 to 60 litres per day.

Table 6.2 The masses of nitrogen supplied by the irrigation water per tree over a three-month period during January to March as influenced by the daily water requirement of 20 to 100 litre per tree per day.

Concentration NH ₄ -N + NO ₃ -N mg per litre water	Water requirement in litres per day				
	20	40	60	80	100
10	18	36	54	72	90
15	27	54	81	108	135
20	36	72	108	144	180
25	45	90	135	180	225
30	54	108	162	216	270

Therefore, if water containing 30 mg N per litre is applied to satisfy a requirement of 100 litres per day, 270 g N is applied over this three-month period. This is almost equal to 1000 g LAN per tree applied at the wrong physiological stage.

Untimely applications due to N in the water result in poor fruit quality.

All nitrates and ammonium salts are very soluble in water and cannot be easily, or cheaply removed. The most successful action to reduce the N levels in water requires an input of the whole farming community to reduce N application and leaching.

7. SULPHATE (SO₄)

Like calcium, sulphate is seen as the “good” anion. Sulphur is an essential nutrient element for plants and some plants require more S than P. The presence of sulphate in the water has a much lesser negative effect on the quality than Cl. In the presence of Ca and at high pH levels, SO₄ will precipitate to form the less soluble gypsum. One me SO₄ = 48.03 mg SO₄ = 16.03 mg S per litre water. SO₄ is the “good” anion.

1 me SO₄ = 48.03 mg SO₄ = 16.03 mg S per litre

8. CHLORIDE (Cl)

Chloride is seen as the “bad” anion. Chloride is the most common anion in water and the chlorides of K, Ca, Mg, Na and NH₄ are all very soluble in water.

Chloride is also an essential nutrient element for plants and is required in the splitting of the water molecule during photosynthesis. The requirement is about 3 mg Cl per litre water and is usually easily met. One me Cl = 35.45 mg Cl.

Cl is the “bad” anion

1 me Cl = 35.45 mg Cl.

The negative effect of too much Cl in waters used in fertigation and hydroponics can be offset to some extent by including nitrate and calcium in the nutrient solution. One me Ca will offset the effect of 4 me Cl while one me NO₃ will offset the effect of one me Cl.

Dissolved chlorides increase the EC and OP of water to a greater extent than other ions and will also limit production in this way (see 3.2.2 above). Chloride has a greater negative reaction on plant performance than sodium and is the greatest contributor to the so-called “physiological drought” plants experience under salty conditions. This phenomenon is sometimes employed in a positive manner to increase the total dissolved solids in fruit like tomato.

Guidelines for permissible concentrations of Cl in waters:

	Concentration in	
	me per litre	mg per litre
❖ For crops that require chloride free cultivation conditions like flue cured tobacco.	< 0.70	< 25
❖ For chloride sensitive crops (lettuce, peas and beans), mist chambers and container plants.	< 1.50	< 53
❖ Suitable for the most crops including air cured tobacco and for foliar sprays.	< 3.00	< 106
❖ For chloride tolerant crops like lucerne, barley and beetroot	< 5.00	< 175
❖ Overhead irrigation of:		
Almonds, apricots, citrus	< 5.00	< 175
Grapes, potato and tomato	< 10.00	< 355
Lucerne, barley and maize	< 15.00	< 532
❖ Flood irrigation	< 4.00	< 142
❖ Sprinkler irrigation	< 3.00	< 106

Potassium chloride is the cheapest source of potassium but due to the high Cl-content (50%) this source is not always popular. However the comparative mass of chloride applied via the irrigation water is more often than not exceeded by the mass applied via potassium chloride. In table 8.1 the masses of chloride applied via the irrigation water are related to the chloride concentration and the precipitation rate.

Table 8.1 The mass of chloride (kg per ha) applied per ha via the irrigation water at various chloride concentrations of the water and precipitation rates.

Chloride concentration		mm irrigation applied per annum								
mg/litre	me/litre	200	300	400	500	600	700	800	900	1000
25	0.714	50	75	100	125	150	175	200	225	250
30	0.857	60	90	120	150	180	210	240	270	300
35	1.000	70	105	140	175	210	245	280	315	350
40	1.143	80	120	160	200	240	280	320	360	400
45	1.286	90	135	180	225	270	315	360	405	450
50	1.429	100	150	200	250	300	350	400	450	500
75	2.143	150	225	300	375	450	525	600	675	750
100	2.857	200	300	400	500	600	700	800	900	1000

This table therefore shows that when 500 mm of a water containing 50 mg Cl per litre is applied, a mass of 250kg Cl will be added to the soil. This is equivalent to 500 kg potassium chloride per ha. If potassium nitrate were used 250 kg less chloride would have been applied.

The important question is whether this extra chloride would have caused yield losses greater than the difference in prices of potassium nitrate and chloride. The relative sensitivity of crops towards chloride is summarised in table 8.2

Table 8.2 The relative sensitivity of crops towards chloride toxicity.

Sensitive crops	:Strawberries, beans, carrots, lettuce, onions and radish.
Less sensitive crop	:Potato, chilli, cabbage, sweet potato, celery, clover, maize and sugarcane.
Fairly tolerant	:Broccoli, cucumber, tomato, spinach, lucerne en pumpkin types.
Tolerant	:Beetroot, wheat and barley.
Very tolerant	:Sorghum, cotton.

The chloride concentration in the water also influences the suitability of such water for foliar sprays during pest control or foliar feeding. Table 8.3 divides some crops in four categories.

Table 8.3 The maximum concentrations chloride plus sodium (me Cl + me Na) that can be sprayed on the foliage of various crops

me Chloride plus Sodium			
< 10	10 – 20	20 – 40	> 40
Stone fruit	Potato	Cucumber	Cotton
Citrus	Tomato	Maize	Cauliflower
Avocado	Grape	Lucerne	Sunflower
Macadamia	Chilli	Sorghum	Olive
Mango			

9 CARBONATE AND BICARBONATE.

The concentration of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) are reported in me or mg per litre. One me CO_3^{2-} = 30.01 mg CO_3^{2-} and one me HCO_3^- = 61.01 mg HCO_3^- . The CO_3^{2-} and HCO_3^- are in equilibrium with the carbonic acid (H_2CO_3) in solution. The concentrations of these ions are determined by the pH of the water or nutrient solution as shown in table 9.1.

Table 9.1 The concentration of Carbonate Bicarbonate and Carbonic acid at various pH's.

pH	H_2CO_3	HCO_3^-	CO_3^{2-}
9	0.20%	95	4.80%
8	2.30%	9%	0.70%
7	18.05%	1%	0.05%
6	69.9983%	30%	0.0017%

1 me CO_3^{2-} = 30.01 mg CO_3^{2-}
 1 me HCO_3^- = 61.01 mg HCO_3^-

At conditions of standard temperature and pressure (STP), the bicarbonate ion will be in equilibrium with the CO_2 in the atmosphere and the reaction will flow in the direction to transform HCO_3^- to CO_2 and H_2O until equilibrium is reached. The atmosphere contains about 300 mg CO_2 per litre. Under conditions where more than 300 mg is present in the atmosphere (under pressure like in soda water), some CO_2 will dissolve in the water and H_2CO_3 concentration will increase causing the pH to decrease. When the pressure is released the H_2CO_3 will be converted to CO_2 , which will escape into the atmosphere, and the pH will increase.

By decreasing the pH of the water with acids such as nitric acid, the equilibrium is shifted to generate CO₂ that will escape into the atmosphere. Hence the HCO₃⁻ and CO₃²⁻ are changed from “useless” to “useful” ions with only a little change in the EC of the solution. When nitric acid is used, the HCO₃⁻ is displaced by the nitrate ion and when phosphoric acid is applied to acidify the water, the HCO₃⁻ is displaced by PO₄³⁻.

The NO₃-N and/or PO₄ supplied via the acids used to acidify the water must be incorporated into the nitrogen and/or phosphorus requirement of the formulation. Sulphuric acid can also be used, and will supply sulphates, but hydrochloric acid, which adds chlorides to the solution, is seldom used.

Displace the “unwanted” HCO₃ by “wanted” NO₃ or PO₄

Oddly enough, CO₂ gas can also be used to acidify water. This is done by adding carbon dioxide under pressure and the equation is shifted to the left when more CO₂ is dissolved to form carbonic acid.

Under pressure the concentration of CO₂ in the atmosphere is lifted to above the 300 mg per litre level and carbonic acid will form. When the pressure is released the CO₂ will escape (and the equation is shifting to the right, forming CO₂ gas again plus water) until the concentration of the CO₂ is in equilibrium with the CO₂ in the atmosphere, which is about 300 mg per litre. That is why the pH of soda water will increase from 5.00, after opening the can, when the gas escapes into the atmosphere. The same applies to water acidified by CO₂. The pH of the water will increase as soon as the pressure is released. Therefore it can only be used with drip irrigation systems where the water is under pressure until it almost hits the soil.

CO₂ gas can also be used to acidify water

The volumes of acid required to acidify the water will therefore depend on the concentration of carbonates and bicarbonates. Table 9.2 contains the volumes of nitric and phosphoric acid required to “remove” various concentrations of bicarbonates (HCO₃).

Table 9.2 The volumes nitric and phosphoric acid required to neutralize a certain bicarbonate concentration in the water and the milligrams of NO₃-N and PO₄-P per litre added to the nutrient solution in this process.

Phosphoric acid with specifications; 85% purity, a normality of 36.4 and specific density of 1.69

me HCO ₃ per litre water	ml acid per 1000 litre water	mg PO ₄ -P per litre
0.35	10	2.50
0.70	20	5.00
1.05	30	7.50
1.40	40	10.00
1.75	50	12.50
2.10	60	15.00
2.45	70	17.50
2.80	80	20.00
3.15	90	22.50

Nitric acid with specifications; 60% purity, a normality of 13.7 and specific density of 1.36

Me HCO ₃ per litre water	ml acid per 1000 litre water	mg NO ₃ -N per litre
0.135	10	1.75
0.270	20	3.50
0.405	30	5.25
0.540	40	7.00
0.675	50	8.75
0.810	60	10.50
0.945	70	12.25
1.080	80	14.00
1.215	90	15.75

To incorporate the carbonates (CO₃) into the above tables, multiply the me CO₃ by two and add that to the value of the bicarbonates.

me CO₃ X 2 = me HCO₃

10 BORON

Boron (B) is an essential micro-element for plant and animal, but is required in very small amounts and can easily reach toxic levels. Water is an important source of boron for plants and forms part of the evaluation parameters for any water source.

Boron is reported as mg B or very seldom as micro mol B (umol B) per litre water. One mg B = 92.51 umol B. When the B concentration in the water is < 0.25 mg B per litre, boron fertilisers will need to be applied at some stage or other. Soil or leaf analyses are useful tools to determine when such applications will be needed.

If the concentration exceeds 1.00 mg of B per litre water, phytotoxicities may occur on boron sensitive plants. In table 10.1 some crops are listed according to their relative sensitivity to excess B in the irrigation water.

1 mg B = 92.51 umol B

Table 10.1 Grouping of some crops according to their relative sensitivity to the concentration of boron (mg B per litre) in the irrigation water.

Sensitive	Slightly Sensitive	Quite Tolerant	Tolerant	Very Tolerant
<1.00	1.01 – 2.00	2.01 – 4.00	4.01 – 6.00	6.01 – 15.00
Apricot	Broccoli	Barley	Beetroot	Asparagus
Avocado	Carrots	Cabbage	Lucerne	Celery
Beans	Chilli	Cauliflower	Sugar beet	Cotton
Citrus	Cucumber	Clover	Tomato	Sorghum
Figs	Lettuce	Maize		
Garlic	Peas	Melon		
Grapes	Potato	Oats		
Onion		Squash		
Peanuts		Tobacco		
Pecan Nut		Turnip		
Persimmon				
Stone fruit				
Strawberry				
Sunflower				
Sweet Potato				
Walnut				
Wheat				

11 CHEMICAL OXYGEN DEMAND
 Natural waters also contain organic matter. The chemical oxygen demand (COD) measures the amounts of dissolved and suspended organic matter in the water and is reported as mg per litre.

A class 1 water refers to the ideal concentration of elements in water that will present no health hazards in life-long consumption.

12 PARAMETERS FOR HUMAN CONSUMPTION
 When drinking water is classified the emphasis is on the possible health hazards when consuming the water over a prolonged period.

A class 2 water refers to the maximum permissible concentration of the analytes for a source that can be consumed for life. However any change in rainfall or season in the catchment area can turn this into a class 3 water.

A class 3 water that cannot be consumed for more than two days running or for more than 12 days per year.

Table 12.1 contains the permissible concentrations of the analytes for the three classes.

Table 12.1 The maximum concentration of the important elements used to classify drinking water into CLASS 1, CLASS 2 and CLASS 3.

Analyte	Class 1	Class 2	Class 3
pH	6.00 to 9.00	5.50 to 9.50	< 4.00 or > 11
Electrical Conductivity mSm ⁻¹	70	300	400
Potassium mg/l	200	400	800
Calcium mg/l	150	200	400
Magnesium mg/l	70	100	200
Sodium mg/l	100	400	800
Sulphate (as SO ₄) mg/l	200	600	1200
Chloride mg/l	250	600	1200

Ammonium (as NH ₄ -N)	mg/l	1.00	2.00	4.00
Nitrate (as NO ₃ -N)	mg/l	6.00	10.00	20.00
Boron	mg/l	0.50	2.00	4.00
Fluoride	mg/l	1.00	1.50	3.00
Hardness (as CaCO ₃)	mg/l	300	650	1300
Total plate count colonies/ml		< 100	<1 000	<10 000
Faecal <i>coliforms</i> colonies/100 ml		0	1	10
Total <i>E. coli</i> colonies /100 ml		0	5	100

Localised deposits of minerals can influence the composition of the water from that area naturally or due to pollution. Table 12.2 contains the permissible concentrations of additional elements for the three classes of drinking water.

Table 12.2 Maximum concentration of additional elements for Class 1, Class 2 en Class 3 waters for human consumption.

		Class 1	Class 2	Class 3
Macro-element	(milligram per litre)			
Aluminium	Al	0.15	0.50	1.00
Barium	Ba	0.50	1.00	2.00
Bromide	Br	1.00	3.00	6.00
Cerium	Ce	1.00	2.00	4.00
Copper	Cu	0.50	1.00	2.00
Iodine	I	0.50	1.00	2.00
Lithium	Li	2.50	5.00	10.00
Manganese	Mn	0.05	1.00	2.00
Uranium	U	1.00	4.00	8.00
Zinc	Zn	1.00	5.00	10.00
Micro-element	(micro-gram per litre)			
Antimony	Sb	50	100	200
Arsenic	As	100	300	600
Beryllium	Be	2	5	10
Bismuth	Bi	250	500	1000
Cadmium	Cd	10	20	40
Chromium	Cr	100	200	400
Cyanide	CN ⁻	200	300	600
Gold	Au	2	5	10
Lead	Pb	50	100	200
Mercury	Hg	5	10	20
Molybdenum	Mo	50	100	200
Nickel	Ni	250	500	1000
Selenium	Se	20	50	100
Silver	Ag	20	50	100
Tallium	Tl	5	10	20
Tellurium	Te	2	5	10
Tin	Sn	100	200	400
Titanium	Ti	100	500	1000
Vanadium	V	250	500	1000
Wolfram (Tungsten)	W	100	500	1000

13 PARAMETERS OF DRINKING WATER FOR RUMINANTS AND FOWL

Table 13.1 contains some of the elements, which will determine the suitability of a water source for animal and fowl consumption. This

list is not complete and some birds like ostriches and animals like pigs might be more sensitive. The table only serves as a directive and information on specific species needs to be considered.

Table 13.1 The maximum permissible concentrations of some analytes of water for fowl and ruminants in general.

		Fowl	Ruminants
pH		6.00 to 8.00	5.50 to 8.30
EC mSm ⁻¹		50 to 80	< 300
Total soluble salts (TSS)	mg/l	300 to 500	< 2000
Alkalinity	“	< 1000	< 2000
Aluminium	“	< 5.00	< 5.00
Ammonium nitrogen	“	*	*
Arsenic	“	0.20	0.05
Boron	“	*	5.00
Chloride	“	< 200	< 1000
Phosphate (as P)	“	*	< 0.70
Potassium	“	< 300	< 20
Calcium	“	35 tot 600	< 1000
Cobalt	“	*	< 1.00
Copper	“	0.05	< 1.00
Fluoride	“	*	0.50 - 1.50
Hardness (as CaCO ₃)	“	< 2000	< 2000
Iodine	“	*	< 1.00
Lead	“	< 0.01	< 0.05
Magnesium	“	< 50	< 1000
Manganese	“	< 0.05	< 0.05
Sodium	“	< 50	< 800
Nitrate nitrogen	“	< 10	< 25
Zinc	“	< 2.50	< 5.00
Sulphate (as SO ₄)	“	< 200	< 500
Iron	“	0.40 tot 1.00	< 1.00
Faecal <i>coli</i> colonies per 100 ml		0	0

* = no fixed guidelines as yet.

A pH of less than 6.00 might impair the digestion and utilization of medication.

If Na > 50 mg/l, 14 mg Cl/l might impair production of fowl.

High concentrations of sulphates result in too wet faeces with fowls, which could be aggravated by more than 50 mg Na and Mg. Too much copper gives a bitter taste to the water and could cause liver damage to fowls.