WATER CONSERVATION TECHNICAL BRIEFS

TB14 – Salinity control

SAI Platform

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WATER CONSERVATION

TECHNICAL BRIEFS

TB14 – Salinity control

Salts are chemical compounds generally made up of sodium, magnesium, calcium, chloride, sulphate, bicarbonate or carbonate ions. Salinity is the concentration of all soluble salts in water or in the soil. It can dramatically reduce agricultural productivity, as high salt levels can limit crop growth and even kill plants. However, saline waters can be used effectively for the production of selected crops under the right growing conditions. This technical brief describes salinity quality problems and outlines different practices in managing them.

The structure of this technical brief is as follows: Section 1 describes salinity and its impact on agriculture. Section 2 outlines the reasons that cause salinity. Section 3 explains the effect of salinity on crops and soils. Section 4 explores ways to measure salinity. Section 5 depicts a framework that allows farmers to identify salinity issues at farm level. Section 6 presents different measures to control and manage salinity in farms such as irrigation methods and field management strategies. Section 7 outlines a case study of farmers in Egypt who grow crops under controlled salinity conditions. Finally, Section 8 provides references and recommends some further reading.

Contents

SECTION 1: WHAT IS SALINITY?

Salinity is the accumulation of salts (often dominated by sodium chloride ($NaCl$)) in soil and water to levels that can have negative impacts on agriculture.[1] Yield reductions occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in water stress for a significant period of time.[2]

Salinity can have negative impacts on farmers. Some impacts include reduced agricultural production, reduced farm income, reduced options for production, reduced water quality for livestock and irrigation use, reduced productivity of agricultural land, animal health problems e.g. saline water supply, farm machinery problems (rusting), breakdown of soil structure, increased erosion and nutrient loss, loss of beneficial native flora and fauna.[3]

SECTION 2: WHAT CAUSES SALINITY?

Salinity can be produced by the natural occurrence of salts in the landscape, for example salt marshes, salt lakes, tidal swamps or natural salt scalds.[4] It can also be caused by irrigation with saline water, uneven water distribution, salts accumulated in the root zone and salinisation of root zone from shallow water tables,[5] increased rates of leakage and groundwater recharge causing the water table to rise.[6] Rising water tables can bring salts into the plant root zone which affects both plant growth and soil structure. The salt remains behind in the soil when water is taken up by plants or lost to evaporation.

During repeated irrigations, the salts in the irrigation water can accumulate in the soil, reducing water available to the crop and hastening the onset of a water shortage.[7]
Recharge rates in irrigation areas can be much higher than dryer areas due to leakage from both rainfall and irrigation. This potentially causes very high salinisation rates. Water tables within two metres of the soil surface indicate the potential for salts to accumulate at the soil surface.

Inefficient irrigation and drainage systems are a major cause of excess leakage and increase the risk of salinity and waterlogging in irrigation areas. Poor water distribution in paddocks results in some areas being under-irrigated, causing salts to accumulate (where water tables are high) and other areas being over-irrigated and waterlogged.

Continual under-irrigation also increases salinity as salts contained in the irrigation water need to be flushed or leached periodically to prevent them accumulating to levels that limit productivity. Inappropriate matching of crop, soil type and irrigation methods can also cause excessive leakage. For example, irrigating high water-use crops using inappropriate irrigation methods should not be carried out on permeable soils (high sand content). Other factors which influence leakage rates include soil type, climate and the amount (or removal) of deep-rooted perennial vegetation. Replacing deep-rooted perennial pasture with irrigated annual crops reduces the level of evapotranspiration as rates are low following cultivation and during fallow periods. As a result, more water will infiltrate the soil profile and enter the water table. (See figure below the saline regime recharge, discharge and salinity processes in the groundwater hydrologic cycle.)

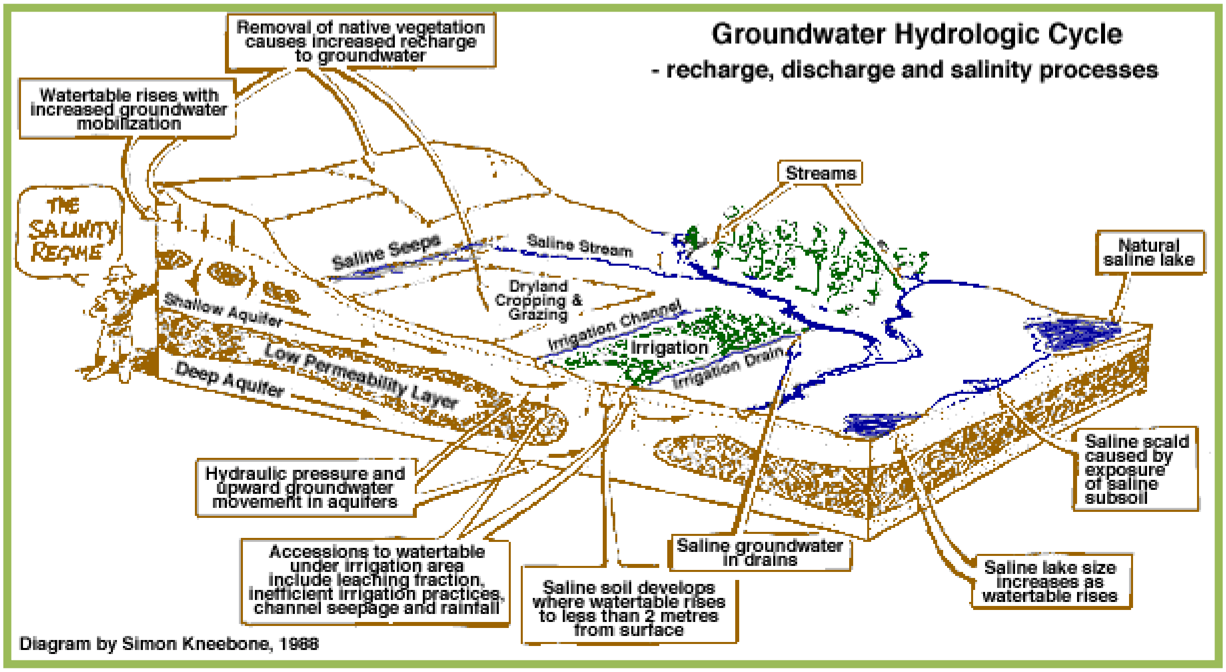

Figure 1 : Groundwater Hydrologic Cycle - recharge, discharge and salinity processes Source: http://www.dse.vic.gov.au/dpi/vro/vrosite.nsf/pages/water-gwater-hydrodiag

Waterlogging can also exacerbate the effect of salinity as plant roots are unable to exclude sodium and chloride due to the increased rates of transport of these ions, and concentrations in the plant shoot increase. Poor aeration also affects soil biology responsible for converting nutrients to their plant available form, causing nutrient deficiencies. [8]

SECTION 3: THE EFFECT OF SALT ON PLANTS AND SOIL

Plants are adversely affected by salinity in several ways. The most important of these is the osmotic effect, which limits the ability of plants to take up water.[9] Under normal conditions, plants readily obtain water from the soil by osmosis (movement of water from a lower salt concentration outside the plant to a higher salt concentration in the plant). As soil salinity increases this balance shifts making it more difficult for plants to extract water. [10]

As a general guide, chloride and sodium ions in the salts do the most damage to plants. Irrigating with water high in these salts can be detrimental to plant growth, affect plant yields and ultimately threaten the plant's survival. [11] Soil salinity has the following adverse impacts which lead to poor plant health, a loss of productive species and dominance of salt-tolerant species: [12]

- increasing salt in the soil increases the osmotic pressure. This results in reduced water availability and reduced growth.
- some elements or ions, especially sodium (Na), chloride (Cl) and boron (B), when in excess are toxic to crops
- high proportions of sodium (Na) in relation to calcium (Ca) and magnesium (Mg) can adversely affect soil structure, and thus limit water, air and root movement in the soil
- altered nutrient interactions e.g. reduced availability of some elements.[13]

Water salinity impacts on plants and animals to varying degrees depending on their salinity tolerance levels. [14] Symptoms vary with the growth stage, being more noticeable if the salts affect the plant during the early stages of growth. In some cases, mild salt effects may go entirely unnoticed because of a uniform reduction in growth across an entire field.[15] The plant symptoms are similar in appearance to those of drought, such as wilting, or a darker, bluish-green colour and sometimes thicker, waxier leaves. Excess sodium accumulation in leaves can cause leaf burn, necrotic (dead) patches and even defoliation. Plants affected by chloride toxicity exhibit similar foliar symptoms, such as leaf bronzing and necrotic spots in some species. Defoliation can occur in some woody species. [16]

Figure 2: Salinity toxic effect on citrus

Some crops such as barley, wheat and corn are known to be more sensitive to salinity during the early growth period than during germination and later growth periods. Sugar beet and safflower are relatively more sensitive during germination, while the tolerance of soybeans may increase or decrease during different growth periods depending on the variety.[17]

SECTION 4: HOW TO MEASURE SALINITY

Types of salinity[18]

Salinity can be due to water salinity or soil salinity.

Water salinity

Water salinity is usually measured by the TDS (total dissolved solids) or the EC (electric conductivity). TDS is sometimes referred to as the total salinity and is measured or expressed in parts per million (ppm) or in the equivalent units of milligrams per litre (mg/L).

- Salinity can be quantified as the amount of salt in milligrams per litre of water (mg/L), often expressed as parts per million (ppm).[19]
- The electrical conductivity of the water can be measured using an EC meter such as the hand-held type shown here – the greater the conductivity, the higher the salt load. Salinity can be reported as EC units, the same as microsiemens per centimetre (µS/cm). Other units sometimes used are millisiemens per centimetre (mS/cm) and decisiemens per metre (dS/m).[20]

A small, handheld meter is invaluable for checking the salinity of irrigation water and monitoring changes through the season. If irrigation water exceeds an EC of 0.8 dS/m (this is equivalent to 500 ppm or 500 kg of salt in 1 megalitre of water) a full chemical analysis, interpreted by a technical expert, should be undertaken and professional irrigation management advice sought. If salinity is present, depending on the actual EC level and the soil type, consider irrigating at night to avoid high evaporation rates which cause salts to concentrate. Avoid leaf contact (e.g. use drip and not overhead sprinkler), maintain low soil moisture deficit (making it easier to flush salts from the root zone), ensure good subsurface drainage and dilute saline water with less salty supplies or consider growing salt-tolerant crops.

Guidance is available on crop tolerance for water salinity; however this is highly dependent on soil types and the degree of associated waterlogging. Expert advice should be sought.

Soil salinity

Sometimes high soil salinity can be found when the water table is low and the salinity of the irrigation water is also low.

Salinity levels in the soil are measured in a 1:5 soil solution (1 part soil to 5 parts water). These are called EC 1:5 readings. The heavier the soil texture (e.g. clay) the more sensitive the crop is.

Thus EC 1:5 readings need to be adjusted for soil texture to reflect local conditions. The adjusted measurements are called 'saturation extract' or EC_{se}.

In case of soil salinity, check the leaching efficiency of the irrigation system. Also check the fertiliser programme – certain fertilisers such as muriate of potash can have a strong influence on soil salinity.

Equipments to measure root-zone salinity

Salinity meters measure the electrical conductivity of water which is related to the total dissolved salts present. They do not provide information on the types or ratios of soluble salts present. [21] The intended use of the water sampled determines the acceptable salt level. Not all salts are detrimental and in appropriate proportions salts improve soil structure and do not affect water quality. For example, calcium carbonate may improve soil structure and soil pH.

There are now several types of equipment that irrigators can use to directly measure root-zone salinity throughout the year. Being able to measure and monitor salinity levels throughout the year is useful where salinity is an increasing problem and on-going changes need to be monitored.

Electrical conductivity meter: A pocket-sized, electrical conductivity is accurate enough for preliminary estimates of water salinity and is suitable for most farm purposes provided it has an adequate measurement range. These salinity meters generally have a range of 0–20 dS/m, which is suitable for testing most surface water. However, some groundwater may be above 20 dS/m and will require diluting or laboratory testing. It is recommended to conduct laboratory testing if it is the first time the water is being used. Laboratory testing is also required to verify high surface-water readings. [22]

Figure 3: Wetting front detector
www.thescientistsgarden.com/

Suction cups:[23] A suction cup is a custom designed ceramic cup glued to a short length of casing, housing an extraction tube with a two-way stopcock. It is used to extract soil water over a range of soil moisture conditions from 0-100 kPa. Once under vacuum, the suction cup draws moisture from the surrounding soil and stores it in the inert ceramic cup. The advantage of using suction cups is that they allow growers to monitor salinity levels frequently, which gives a better idea of the actual variation in soil salinity as it occurs. This information can assist in making management decisions and may help prevent potential salinity problems.

Figure 4: Suction cups

Wetting front detectors:[24] The wetting front detector was designed to monitor water movement through the soil to assist irrigation scheduling. In

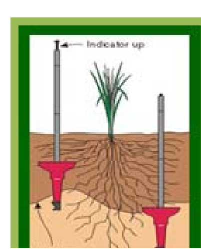

Figure 5: Wetting front detectors

addition, growers are beginning to use the tool to monitor nutrients and salt. A specially shaped funnel and filter is buried at the required depth, and collects soil water as the wetting front of an irrigation reaches this depth. The wetting front detector needs to be placed at depths where there will be fairly strong wetting fronts from irrigation, because it samples when the soil is wetter than 3 kPa. The arrival of the wetting front is indicated by a float mechanism fitted into the funnel and reaching to the surface.

Soil Salinity Sensor - Ceramic element:[25] Soil salinity sensors are ideal for efficient in situ field monitoring of soil salinity with minimal disturbance to the soil profile. At a selected depth, sensors can monitor salinity with high accuracy over a long period. The soil salinity sensors are also suitable for use with soil columns in the laboratory. The soil salinity sensor can be connected to the Salinity Sensor with the Smart Logger. Dynamic changes in soil salinity can be recorded at regular intervals of time.

Figure 6: Soil salinity sensor

Recommendations on when to monitor[26]

- Before using new irrigation water sources (dams, groundwater bores and drainage water), to establish suitability and a baseline measurement.
- When irrigating with saline water which may need to be shandied to dilute salts and prevent damage to crops and pastures.
- If you have any concerns about the quality of the water supply.
- During drought periods when low water volume and high evaporation of water sources may concentrate salts.
- When the water source has not been used for an extended period of time.
- If re-using drainage water which may pick up salt as it flows over salty ground or areas with shallow water tables.
- Following ‘fresh’ in-river flows (a flushing event following rainfall, particularly in storms), especially when flows have been low for some time.
- If dam water appears clear, as high salinity levels will cause suspended sediment to settle out.
- If water tables are high in the area, as saline groundwater may seep into dams, channels and rivers.
- If saline discharge sites occur in the areas, as salts may wash into the water source.
- In case of dairy farms, if stock refuse to drink the water, are scouring for no apparent reason, or production declines.

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Under normal conditions, water testing and/or monitoring monthly should be sufficient. During extended hot dry periods, more frequent testing is advisable as water salinity can change quickly.

Recommendations for sampling and testing[27]

Collecting and testing water salinity using a salinity meter

1. Collect the water sample

- Thoroughly mix the water to be tested before taking a sample.
- Dip a sample container into the water being tested and rinse thoroughly.
- Allow the container to half fill with water.

2. Test the water using the salinity meter

- Calibrate the meter before any testing. Remove the meter cap and switch on the meter.
- Immerse the salinity meter about 25 mm into the sample, so that the meter electrodes are covered. (If testing free water in the paddock do not rest the end of the meter in the sediment on the bottom.)
- Swirl the meter slowly and allow the display to stabilise (it takes up to 20 seconds to adjust for the temperature), then read the number on the meter.
- Record this result and convert it to the desired units.
- Wash electrodes of the meter with de-ionised or rain water, dry, switch off and replace the cap.
- Compare the result to the salinity with tolerance limit for the particular purpose of the water.

SECTION 5: ASSESSMENT OF SALINITY OF IRRIGATION WATER[28] AND MEASUREMENT TOOLS

The following diagram can help farmers to assess a significant salinity problem in the farm area.

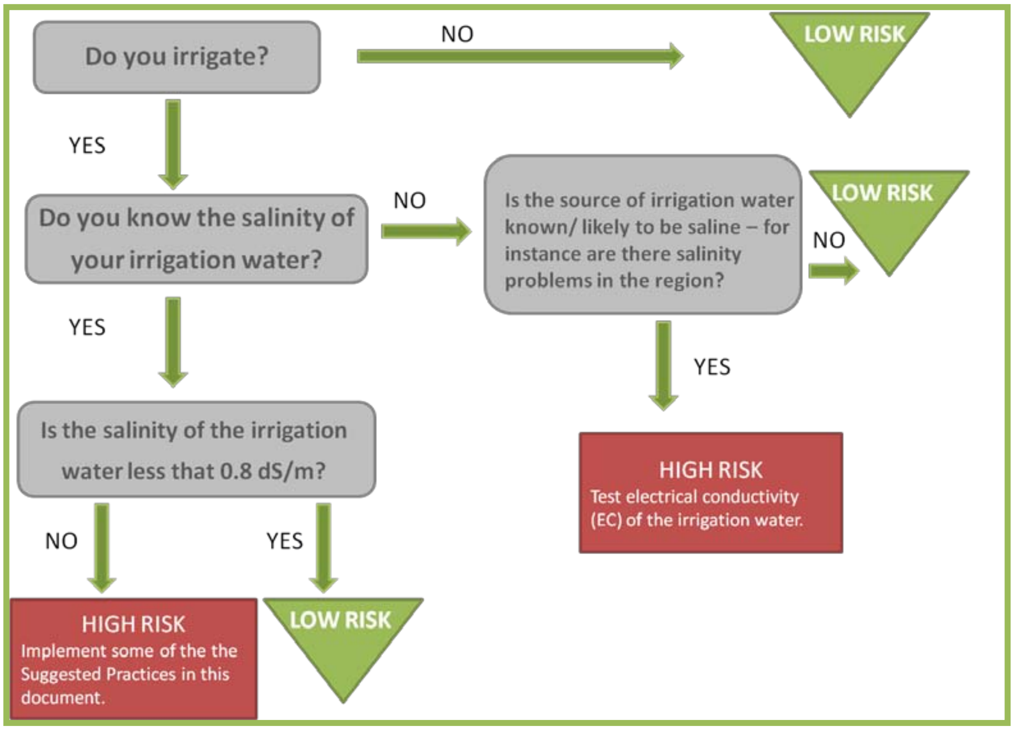

Figure 7: Salinity of irrigation water assessment

Source: Adapted from Lovell, J. (Ed.) (2006) Guidelines for Environmental Assurance in Australian Horticulture. Horticulture Australia Ltd, Sydney. http://www.eksa.com.au/Rangelands-bmpwiki/GetFile.aspx?File=HAL1dSalinity.pdf

Section 6: Practices to control salinity

The following section suggests some practices to control salinity. Practices include minimisation application of salts, choosing the right site and crops and employing good soil/water management (drip irrigation, irrigation scheduling, seedbed placement).

Minimise application of salts

An option to minimise the effects of salinity is to minimise irrigation applications and the subsequent accumulation of salts in the field. This can be accomplished through converting to a rainfed production system; maximizing effectiveness of precipitation to reduce the amount of irrigation required; adopting highly efficient irrigation and tillage practices to reduce irrigation applications required; and/or using a higher quality irrigation water source (if available). Since some salts are added through fertilisers or as components (or contaminants) of other soil additives, soil fertility testing is warranted to refine nutrient management programmes. [29]

Crop selection

Some relatively salt tolerant crops (such as barley and sugarbeet) are more salt sensitive at emergence and early growth stages than in their later growth stages. Currently crop breeding programmes are addressing salt tolerance for several crops, including small grains and forages.
Some field crops are particularly susceptible to particular salts or specific elements or to foliar injury if saline water is applied through sprinkler irrigation methods.

Tolerances to salinity in soil solution and irrigation water and tolerances to Na, Cl, and B are listed for various crops in references listed in the Additional Information Resources section. [30]

Drip irrigation

Surface drip irrigation and subsurface drip irrigation (SDI) methods can be very effective in applying irrigation without leaf wetting.

Some salts, including calcium and magnesium carbonates that contribute to water hardness, merit special consideration for subsurface drip irrigation systems. These salts can precipitate out of solution and contribute to significant clogging of drip emitters and other components (such as filters). Water quality analysis, including acid titration, is necessary to determine appropriate SDI maintenance requirements. Common maintenance practices include periodic acid injection (shock treatment to prevent and/or dissolve precipitates) and continuous acid injection (acid pH maintained to prevent chemical precipitation). [31]

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Irrigation scheduling

Managing irrigation schedules (amounts and timing) helps to keep salt accumulations dispersed and away from plant roots, provides for better root uptake of nutrients, and offers improved protection from short-term drought conditions. [32]

Light, frequent irrigation applications can result in a small wetted zone and limited capacity for dilution or leaching of salts. When salt deposits accumulate near the soil surface (due to small irrigation amounts combined with evaporation from the soil surface), crop germination problems and seedling damage are more likely. In arid and semi-arid conditions a smaller wetted zone generally results in a smaller effective root zone; hence the crop is more vulnerable to salt damage and to drought stress injury.

Seedbed placement

In some operations, seed placement can be adapted to avoid planting directly into areas of highest salt accumulation. Row spacing and water movement within the soil can affect the amount of water available for seedlings as well as the amount of water required and available for the dilution of salts. [33]

Maintaining soil organic matter

By improving and preserving soil structure and permeability, organic matter helps to support ready movement of water through the soil and maintain higher water holding capacity of the soil. Organic matter can contribute to a higher cation exchange capacity (CEC) and therefore lower the exchangeable sodium percentage, thereby helping to mitigate negative effects of sodium. Where feasible, organic mulches also can reduce evaporation from the soil surface, thereby increasing water use efficiency (and possibly lowering irrigation demand). Because some organic mulch materials can contain appreciable salts, sampling and analysis for salt content of these products are recommended.[34]

Vegetation can assist in preventing and managing salinity, particularly salinity associated with rising water tables. Deep-rooted plants can assist in preventing rising water tables, by utilising water deep in the soil profile. [35]

Improving drainage[36]

Improve drainage in saline areas, particularly if salinity problems are associated with a rising water table and saline groundwater. If soils are waterlogged, removing excess water can help leach of salt from the root zone to lower levels in the soil profile. Consideration must be given to management of the drainage water.

- Cut-off drains can divert and remove surface water that would otherwise become groundwater recharge. Surface drains should be stabilised with fencing and vegetation cover.

- Raised beds with adjoining furrow drains can improve surface drainage and salt leaching.
- Sub-surface drainage can reduce waterlogging and increase the leaching of salt.
- Care is needed when considering drainage options as drains in dispersive soils can lead to soil instability and severe erosion.

Groundwater salinity

To minimise the chances of salinity problems, the water table should be kept two metres or more below the soil surface. In some areas this is an issue that requires regional management, such as establishing spear points, tile drains or groundwater pumps to increase the depth of the water table.

The water table should also be monitored over time to check if it is stable or rising. If the water table is high (within 2 m) then artificial subsurface drainage may be needed. If water tables are not yet high but are rising, subsurface drainage may be needed in the future. It is also recommended to work on improving irrigation efficiency.

Irrigation leaching[a]

A classic solution to salinity management in the field is through leaching accumulated salts below the root zone. This is often accomplished by occasional excessive irrigation applications to dissolve, dilute and move the salts. The amount of excess irrigation application required (often referred to as the "leaching fraction") depends upon the concentrations of salts within the soil and in the water applied to accomplish the leaching.

In areas affected (or at risk of being affected) by salinity irrigation requires careful management. It is a good idea to seek professional advice before developing an irrigation system in these situations. Applying a leaching fraction can flush salts out of the topsoil. Rainfall may act as a leaching fraction. However, excessive leaching fractions can worsen the process of salinisation by causing the water table to rise, so they need to be carefully managed. [37]

Where irrigation water quantity is limited, sufficient water for leaching may not be available. The combined problem of limited water volume and poor water quality can be particularly difficult to manage. [38] Soil additives and field drainage can be used to facilitate the leaching process. Site specific issues, including soil and water chemistry, soil characteristics and field

[a] A commonly used equation to estimate leaching fraction requirement (expressed as a percent of irrigation requirement) is: Leaching fraction = (electrical conductivity of irrigation water) / (permissible electrical conductivity in the soil) X 100 %

layout, should be considered in determining the best approach to accomplish effective leaching. For instance, gypsum, sulphur, sulphuric acid, and other sulphur containing compounds, as well as calcium and calcium salts may used to increase the availability of calcium in soil solution to "displace" sodium adsorbed to soil particles and hence facilitate sodium leaching for remediation of sodic soils. In soils with insufficient internal drainage for salt leaching and removal, mechanical drainage (subsurface drain tiles, ditches, etc.) may be necessary. [39]

Section 7: Case studies

Salinity Management options in Egypt[40]

Egypt is a predominantly arid country and the scattered rain showers in the north can hardly support any agricultural crops. Direct use of drainage water for irrigation with salinity varying from 2 to 3 dS/m, is common in the districts of Northern Delta where there are no other alternatives or in areas of limited better water quality supply. Farmers in Beheira, Kafr-El-Sheikh, Damietta and Dakhlia Governorates have successfully used drainage water directly for periods of 25 years to irrigate over 10’000 ha of land, using traditional farming practices. The soil texture ranges from sand, silt loam to clay with calcium carbonate content of 2 to 20% and very low in organic matter. The major crops include clover "Berseem", rice, wheat, barley, sugarbeet and cotton. Yield reductions of 25 to 30 percent are apparently acceptable to local farmers. Yield reductions observed are attributed to waterlogging and salinisation resulting from over-irrigation and other forms of poor agricultural, soil and water management.

Pilot studies carried out in Kafr el Sheik and Beheira Governorates showed that by applying appropriate management practices listed below drainage water of salinity 2 to 2.5 dS/m can be safely used for irrigation without long term hazardous consequences to crops or soils such as

- crop selection,
- use of soil amendments,
- deep ploughing,
- tillage for seedbed preparation,
- land levelling,
- minimum leaching requirements,
- mulching,
- organic manuring.

SECTION 8: REFERENCES AND FURTHER READING

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Dana O. Porter, P.E. and Thomas Marek, P.E.
http://www.ksre.k-state.edu/irrigate/OOW/P06/Porter06.pdf

Irrigation water quality: Critical Salt Levels for Peanuts, Cotton, Corn and GrainSorghum
Texas Cooperative Extension and Texas Agricultural Experiment Station
http://lubbock.tamu.edu/cotton/pdf/irrigwaterqual.pdf

Irrigation Water Quality Standards and Salinity Management
http://itc.tamu.edu/documents/extensionpubs/B-1667.pdf

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Irrigation Water Salinity and Crop Production
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The Use of Saline Waters for Crop Production - FAO Irrigation and Drainage
Food and Agriculture Organization (FAO) of the United Nations,Paper 48
http://www.fao.org/docrep/T0667E/T0667E00.htm

Evolution, Extent and Economic Land Classification of Salt Affected Soils
Prognosis of Salinity and Alkalinity - FAO Soils Bulletin 31
http://www.fao.org/docrep/x5870e/x5870e04.htm#TopOfPage

Irrigation with Wastewater
http://www.fao.org/docrep/T0551E/t0551e07.htm

USDA-ARS George E. Brown, Jr. Salinity Laboratory
Handbook No. 60 Saline and Alkali Soils (out of print, but available online)
This website contains information about the effects of salts on soil and plants, the methods of sampling, monitoring, and measuring salinity, the use of saline drainage water in irrigation, the methods of managing salinity and the use of models in salinity assessment
http://www.ars.usda.gov/Services/docs.htm?docid=10158

Yiasoumi, W., Evans, L. and Rogers, L. (2005) 'Farm water quality and treatment.'
This guide describes common water quality issues, and methods of treating them.
www.dpi.nsw.gov.au/__data/assets/pdf_file/0013/164101/farm-water-quality.pdf

Gibbs, S. (2000) 'How do I test water salinity?'
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Available at www.dpi.nsw.gov.au/agriculture/resources/soils/salinity/general/test

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[1] Irrigation salinity – causes and impacts
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[22]http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/303666/Measuring-water-salinity.pdf

[23] Salinity Management Practice Guidelines
Managing root-zone salinity for irrigated horticultural crops in winter rainfall zones of Australia
Tapas Biswas, John Bourne, Gerrit Schrale and Michael McCarthy
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