ENVIRONMENT & HEALTH PROTECTION GUIDELINES
On-Site Sewage Management for Single Households

Consideration of soil sodicity when assessing land application of effluent or greywater

Dr Robert A. Patterson

Lanfax Laboratories, Armidale

Introduction

The topic of *soil salinity* has been addressed in a separate paper and dealt with all the inorganic soluble salts which may be present in the soil water from time to time. Changes to effluent management may alter the quantity and proportion of the various soluble salts that influence plant physiology and soil structural properties. The various concentrations of particular soluble salts in the effluent or greywater may affect the soil in different ways, for example calcium induces flocculation while sodium favours dispersion and loss of structural stability. *Soil sodicity* is concerned with that part of salinity which targets the effects of sodium as a proportion of the soluble salts and the specific effects its presence and concentration impart to the soil. Sodium salts are always very soluble, many times more soluble than calcium or magnesium salts and this solubility presents special problems. Soils may be saline and sodic or non-saline and sodic.

Measuring Sodicity

Sodium salts occur as part of the total soluble and exchangeable inorganic salt load in a soil. Whether these salts have been derived from geological weathering or applied to land as part of a wastewater reuse program does not detract from the potential problems that sodium salts may have on both the vegetation and the soils.

A *sodic soil* is one containing sufficient exchangeable sodium to adversely affect soil stability, plant growth and/or land use (Charman & Murphy, 2000). When the adsorption of sodium on the surface of clays exceeds 6% of the total CEC, the soil is sodic and subject to serious structural degradation (Rengasamy & Olsson, 1991). Most Australian researchers use exchangeable sodium percentage (ESP) values of 5% or 6% as the critical value compared with the U.S.A. soils where ESP 15% is used because of the higher calcium content in those soils. Australian soils are more highly leached and have a natural low electrolyte level, at which level sodium favours dispersion of soil aggregates.

In simple terms, the inorganic (clay) and organic colloids in the soil (particles less than 2 um) have nett negative charges on their surfaces and these negative charges attract positively charged ions (cations) from the soil solution in order to attain electrical neutrality. The major cations in the soil are Ca^{2+}, Mg^{2+}, Na^+, K^+, H^+, and Al^{3+} as discussed under the topic of "salinity" and each of these can bond to the negatively charged sites to reduce electronegativity. Sodium is not as effective as other cations in neutralising the charge on the colloid, thus individual colloids continue to repel each other and stay in solution (Brady, 1990). The total negative charge on the soil is called the cation exchange capacity.

The CEC of a soil is measured in the laboratory, no suitable field measurement procedure is available. Several methods are in common use as outlined in Raymont & Higginson (1992). It is important to understand the difference between the measurement of the exchangeable cations Ca^{2+}, Na^+, Mg^{2+} and K^+ in the soil with or without inclusion of the soluble salts in the soil solution, and measurements made of the same four cations plus the H^+ and Al^{3+} cations. The term effective cation exchange capacity (ECEC) refers to the former measurement where the four cations are accounted for, together with the soluble salts of the soil solution, while the CEC refers to the latter when H^+ and Al^{3+} are also measured. It is often not clear from laboratory reports which method has been used and reporting the method is critical to accuracy of the results where comparisons are to be made.

After measuring CEC of the soil, the proportion of exchangeable sodium relative to summation of exchangeable cations is calculated to provide the ESP for the soil, as set out in Equation 1. This calculation (units of %) is used to indicate the likely effects that a soil may have with respect to structural stability, because Na^+ ions favour dispersion and Ca^{2+} and Mg^{2+} favour flocculation (opposite to dispersion). Values above 6% are more likely to favour soil instability.

The unit centimoles of charge per litre (cmol(+) kg^{-1}) is equivalent to the old term milliequivalents per 100 g (meq/100 g) and can be calculated by dividing the concentration in mg kg^{-1} (or parts per million) by ten times the equivalent weight of the element. The equivalent weight is the atomic weight divided by the number of charges on that ion. For example, the equivalent weight of calcium (Ca^{2+}) is the atomic wt (40.08) divided by the number of charges (2), giving 20.04 g, thus 120 mg kg^{-1} is 6.0 cmol(+) kg^{-1}.

Soils which have more than 6% ESP are considered susceptible to structural stability problems related potential dispersion as discussed above. Other factors may enhance or limit that potential and 6% ESP should not be taken absolutely, but examined in context with potential ameliorating measures such as the addition of lime, dolomite or gypsum, or land management options. Irrigation rates, leaching fractions and appropriate design calculations such as long term application rates also interplay with soil properties that influence structural stability.

Quirk and Schofield (1955) determined the threshold electrolyte concentration of the soil solution required to prevent dispersion as set out in Equation 2. They reported that permeability could be maintained even at high ESP provided EC of the soil solution is above the critical threshold level. Adding lime or gypsum increases the EC and reduces the potential for dispersion. Lime increases pH (more alkaline) but gypsum has no pH effect.

Sodium adsorption ratio (SAR) is the term that applies to the ratio of sodium ions to calcium and magnesium ions in water. The ratio is a numerical value with no units, see Equation 3.

Rengasamy *et al.*, (1984) report that the soil ESP is approximately twice the SAR of a 1:5 soil water suspension. However, differences in methods of extraction and variations in the soil properties require caution in accounting for the exchangeable cations which may be displaced from the negatively charged clay or organic colloids when influenced by a different electrolyte solution or sodic irrigation water. The term SAR applies to water and ESP applies to soil and their different calculation formula infer they are measuring different properties.

Effects of Sodium on Soil Properties

Six major effects of sodicity impinge upon the soil's structural stability and physical properties.

1 High levels of sodium at low soil EC values cause or enhance swelling and dispersion of clay particles.

Equation 1
$$ESP \; (\%) \; = \; \frac{[Na^+]}{\sum exch.cations} \times \frac{100}{1}$$
where the units of concentration are cmol(+)/kg or meq/100g

Equation 2
$$TEC \; = \; [0.56 \; x \; (\frac{Na^+}{Ca^{2+}})]$$
where TEC conc. of Na^+ Ca^{2+} in cmol(+)/L

Equation 3
$$SAR \; = \; \frac{[Na^+]}{\sqrt{\frac{([Ca^{2+}]+[Mg^{2+}])}{2}}}$$
where [ ] represents the concentration of cation in cmol(+)/L
note halving sum of $[Ca^{2+}]$ and $[Mg^{2+}]$ before taking square root

2 Dispersion results in the breakdown of chemical and electrical bonds in the soil causing soil crusting, loss of macropores and blocking of pores by clay particles (Shaw, 1999), including water logging, poor infiltration, and reduction in plant available water (Rengasamy & Churchman, 1999).

3 When salinity is low, a soil high in exchangeable Na^+ is alkaline, causing the organic colloids to disperse still more (Leeper & Uren, 1993). The loss of these organic colloids in the drainage water is a loss of important nutrients.

4 When saline-sodic soils are leached with rainwater, clay dispersion in the surface layers leads to water logging and soil erosion (Rengasamy & Olsson, 1993)

5 Sodium salts are toxic to plants, interfering with the osmostic pressure, the symptoms observed as dehydration and death of leaf margins.

6 Dispersion increases erosion hazard and may lead to piping, tunnelling and gully formation in susceptible soils.

Rengasamy & Olsson (1991) stated that the sodicity of the B horizon of many of the soils used for irrigated agriculture is responsible for slow rates of water and nutrient transport, anoxic (no oxygen) and suboxic conditions and high soil strength restricting root growth. With increasing EC at depth and the increased occurrence of carbonates and the high clay content, dispersion and swelling may be suppressed.

Types of Sodic Soils

Four major sodic soils are recognised in Australia and are described by Rengasamy & Olsson (1991) according to their ESP (Eqn 1) and whether the EC of the soil solution exceeds the threshold electrolyte concentration (TEC) (Eqn 2) as:

- saline sodic soils   ESP>6, EC>TEC
- alkaline sodic soils   ESP>6, EC<TEC, pH>8.0
- neutral sodic soils   ESP>6, EC<TEC, pH 6.0-8.0
- acidic sodic soils   ESP>6, EC <TEC, pH<6.0

Further description of these soils is outside the scope of this paper, suffice to suggest that the structural instability, dispersion and loss of permeability will be common problems from the excess sodium in the soil profile whether from effluent or greywater.

Typical Sodic Values

The ESP value of 6%, calculated using Equation 1 from laboratory analysis of soil samples is used in Australia as the critical sodium level above which soils may exhibit dispersion and loss of structural stability, including loss of permeability. However, other considerations of the threshold electrolyte concentration, clay content, and calcium may influence dispersibility. The aim of effective effluent irrigation management is to work to keep the ESP below 6% or maintain the EC above critical values.

When interpreting ESP values of soils for effluent or greywater application, it is important to appreciate the CEC of the soil and the relative concentrations of all the cations. In many soils, elevated ESP values result when Ca^{2+} and Mg^{2+} levels are below normal plant requirements. Often, adding organic matter, increasing pH and adding Ca^{2+} or Mg^{2+} or both to a soil to overcome plant deficiency levels may reduce the ESP to below 6%, making the soil more structurally stable and more favourable to effluent or greywater application.

Saline subsoils dominated by calcium may have pH values in the range of 7.0 to 8.3. Sodium produces five times as much alkali as calcium (Leeper & Uren, 1993) and sodic subsoils may have pH levels 8.5 to 10 (Foth,1978).

When domestic effluent or greywater is irrigated onto soils, the immediate hazard of the elevated sodium content may cause changes to the soil sodicity status. Domestic effluent typically adds 80 -100 mg L^{-1} Na^+ at a low EC (<1 dS/m). To overcome some of the effects of the effluent, adding Ca^{2+} to a new application area (irrigation site or subsurface drainfield) may avoid initial problems, then over time, regular dosing of either the effluent or the soil with calcium salts may be used to assist long term sustainability.

Australian soil science uses 6% ESP as the value for sodicity but NSW planning law uses 5% ESP for the same purpose. The minor difference is irrelevant for most purposes.

Sources of Sodium Salts From Effluent Application

The application of water, greywater or effluent to land systems introduces to the soil quantities of many salts that cannot be leached from the root zone under normal rainfall. Increases in salt concentration will depend upon the unique combination of soil type, effluent quality and leaching or drainage. With respect to sodium, the amount removed in vegetation is negligible. While measuring the amount of sodium in effluent is important, of greater importance are the relationships of SAR and EC of the effluent and the ESP and EC of the soil.

Table 1 indicates the range of SAR for a variety of domestic wastewaters. Patterson (1994) showed that changes to soil permeability commenced within hours of soils being treated with the increasing SAR of solutions. Instability commenced at SAR 3 (EC 0.9 dS m^{-1}). In some rural areas, the clean water resource poses a significant salinity and sodicity hazard before the addition of chemicals from the house. Since

Table 1. Sodium adsorption ratios for potable water and domestic wastewater

Source of water or effluent	Sodium Adsorption Ratios		
	Min.	Mean	Max.
Town water supplies (coastal)	0.2	1.0	2.3
Town water supplies (inland)	0.4	1.7	4.5
Groundwater (sedimentary aquifer)	0.1	0.9	5.2
Groundwater (granite aquifer	0.5	1.6	3.2
Groundwater (basalt aquifer)	0.7	0.8	2.7
Septic tank effluent	0.7	3.6	9.6
Sewage treatment works effluent	2.6	3.9	5.1
Laundry water (powder detergents)	1.2	9.2	52.1
Laundry water (liquid detergents)	0.02	1.0	4.0

sodium salts are always soluble, reducing the sodium load entering the wastewater is critical to effective effluent management. When such reduction is not possible, increasing Ca^{2+} and Mg^{2+} and adjusting the EC and pH are alternative strategies. Do not neglect the valuable role of organic matter in achieving soil stability and overcoming dispersion.

In many of the examples in Table 1, warning bells start to ring for average values for septic tank effluent, sewage treatment works effluent and more particularly the laundry water (greywater)where powder detergents are used, moreso than with liquid detergents.The other variables in effluent chemistry are the EC of the solution, the overall concentrations of the cations and the pH. With EC levels of about 1.4 dS m^{-1} for septic tank effluent, these electrolyte concentrations may not be high enough to overcome the dispersive effects of the sodium.

The practice of using laundry water to irrigate the garden is not a problem while ever the high sodium, high EC irrigation is maintained. The Na+ flushes other monovalent (K+ , NH4+) and divalent ions (Ca2+, Mg2+) from the exchange sites that are then lost in drainage water. The Na+ saturates the exchange sites. When rainwater enters the soil, the soil solution is dominated by sodium at low EC and dispersion follows, with loss of permeability.

Loss of Soil Permeability

Patterson (1994) examined the effects of treating a range of soils with water of varying SAR (0, 3, 8, and 15) in both field and laboratory trials. The respective EC values were 0.003, 0.914, 1.38 and 2.61 dS m^{-1}. There were significant interactions between soils and treatments. Figure 1 indicates the increasing loss of permeability (soil hydraulic conductivity) with increasing SAR and a small change in electrolyte concentrations.

The clay loam soil was treated with aqueous solutions over three hours and each trial replicated

six times as shown by the six bars for each treatment.

The loss of permeability in such a short time indicates the immediate changes that occur when sodium rich solutions are in contact with a soil. The soil to which Figure 1 applies is a non-saline, non-sodic surface soil. Because sodicity induces dispersion, the clay colloids that move settle in the soil pores in the same way a filter is blocked and cause a physical reduction in permeability. Later treatment with chemicals such as lime or gypsum is unlikely to reverse the clogging, hence the need to modify the effluent's quality. Avoiding laundry detergents with high sodium is the most practical solution.

In subsoil drainfields that become severely affected by dispersion, renovation by chemical means is ineffective and a new drainfield should be constructed elsewhere. Treatment of the new drainfield with lime or gypsum prior to commissioning may reduce the impact of the effluent on the new soil interface. In less susceptible soils, adequate drainfield length is required to cope with the reduced equilibrium permeability induced by sodicity and EC qualities of the effluent. The design of a sustainable effluent application area is based
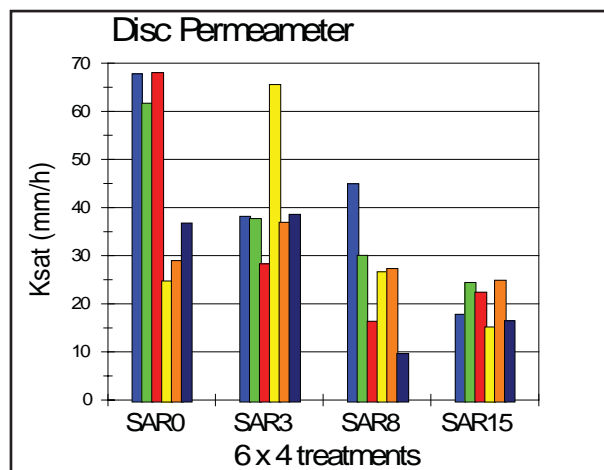

Figure 1. Clay loam surface soil response to solutions of various SAR at EC < TEC

upon understanding the effects of effluent quality on reduced permeability, hence the choice of an appropriate long term application rate.

Amelioration

Amelioration of soil involves reducing the effects of sodium on soil instability. Since sodium salts are always soluble, this process generally involves displacing the Na^+ with divalent ions such as Ca^{2+} or Mg^{2+} and flushing the Na^+ out of the root zone with excess irrigation water. Gypsum is the most common ameliorant used for sodic soils, because no elevation of pH is required. Unfortunately there is no suitable method to allow one to assess the amount of gypsum required for its amelioration, other than trail and error

Rainwater is a cause of dispersion in topsoils because the soil EC falls below TEC, and leads to waterlogging and soil erosion. Therefore, controlling the effect of sodicity in the topsoils is important in the management of effluent irrigation areas. Annual dosing with lime or gypsum maintains a higher soil water EC, and increases Ca^{2+} availability, favouring flocculation.

Irrigation water can be amended with calcium salts to reduce the SAR and increase the EC to induce flocculation in the receiving soil. However, calcium salts are generally only slowly soluble (gypsum solubility is 2.1 g L^{-1}, lime is 0.013 g/L) and additions to the soil need prolonged contact for dissolution over time.

Plants remove only a very small percentage of sodium from the soil and for practical purposes the amount removed is negligible. For this reason, sodium from laundry detergents will not be lessened by growing any specialised vegetation. Some plants may 'tolerate' high levels of sodium, but not actively remove salt through harvesting the crop.

Leaching and drainage removes some of the Na^+ from the soil solution in a given soil horizon (Rengasamy & Olsson, 1993). For this reason the leaching requirements (LR) can be calculated from the known EC of the irrigation water and the acceptable $EC_{1:5}$ of the soil solution. For on-site systems this degree of management is usually omitted but it is crucial for large scale irrigation.

Saline soils have favourable structure because the colloids are highly flocculated (Foth 1978) and Quirk & Schofield (1954) showed that a critical threshold electrolyte concentration (TEC) could be used to assess the potential for flocculation even at high ESP levels.

Simple Dispersion Test

Emerson (1977) stated that it was not possible to obtain a universal relationship between ESP of a soil and minimum concentration of the electrolyte needed to prevent deleterious swelling and dispersion, rather a "dispersion test" was preferred. The Emerson dispersion test (also known as the Emerson Aggregate Test) is now an accepted method of assessing soil dispersion potential.

In the first part of the test, air-dry soil aggregates (peds) 3-5 mm diameter, are immersed in water and the amount of swelling, slaking or dispersion is reported. The test should be performed with water being used for irrigation. In the case of domestic on-site systems a water with SAR 5 and EC 0.9-1.4 dS m^{-1} should be used to reflect the typical quality of septic tank effluent, or greywater of a type that will be used for irrigation.

Class 1 soils completely disperse and Class 2 soils have some dispersion. When there is no dispersion, the second part of the test involves remoulding soil at field capacity and retesting in the same manner. The second part of the test applies to soils which will undergo stresses when moist, such as soils that are ploughed or tilled when wet, and is not usually performed for on-site systems.

The most appropriate soils for effluent or greywater use are those which have water-stable aggregates (they do no fall apart when placed in water), or slake (fall apart - slump, but do not disperse. Slaking can be easily corrected by incorporation of organic matter

The dispersion test only relates to the current status of the soil and not the likely effects that long term application of sodic effluent may have on the soil. It is possible that with an understanding of the soil structural stability, soil texture, ESP and the quality of the effluent (greywater) applied, that some prediction of the long term effects can be made. In large scale irrigation, calculation of leaching requirements and leaching fractions will need to be made and an understanding of the potential for inducing dispersibility factored into management.

Greywater

Water from the laundry or bathroom is called 'greywater' while the water polluted from the toilet known as 'blackwater' Greywater contains hair, skin, blood, body greases, soil, perspiration, body cleaning products and laundry products, each of which imparts a suite of chemicals of various proportions Sodium salts are common in nearly all cleaning products, often at levels that are not favourable for unregulated discharge to soil and may seriously retard vegetative growth and reduce soil permeability. Reducing the quantity of sodium that enters the greywater, by choosing low sodium products, is the only way to avoid problems with sodicity.

Conclusion

The effects of sodium on soil structural stability and plant physiology should not be underestimated. Domestic effluent and greywater provide an increased supply of sodium to displace the beneficial nutrients on the exchange sites, and under conditions of low soil EC cause dispersion. The results are the physical loss of aggregated soil, reduced macroporosity and the loss of permeability. Water logged conditions may follow and with surface crusting and loss of vegetation the erosion hazard increases.

It is important to measure the soil and water quality parameters that indicate the potential detrimental effects of the effluent. For soils these include soil texture, ESP, EC, pH and permeability, while for effluent we measure SAR, EC and pH.

While reducing the sodium load in the waste-water is most effective, the ability to counter the effects of sodium by changing ESP and SAR ratios, increasing soil electrolyte concentrations and manipulating pH allow better utilisation of soils for long term application of effluent. The loss of permeability induced by sodium is perhaps the greatest cause of failure of effluent application areas, particularly subsurface areas where most of the systems operate in a environment of neglect. The loss of permeability caused by dispersion cannot be rectified by chemical means and construction of alternative drainfields is required. For surface applied effluent, the effects of dispersion can be physically remediated and chemically ameliorated to prevent the soils dispersing again.

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For More Information

Author Contact Details

Dr Robert A. Patterson
Lanfax Laboratories
PO Box W90
Armidale NSW 2350
Phone: 02 6775 1157
Fax: 02 6775 1043
Email: rob@lanfaxlabs.com.au

Septic Safe Program

Department of Local Government
Locked Bag 3015
Nowra NSW 2541
Phone: (02) 4428 4179
Fax: (02)1
Email: septicsafe@dlg.nsw.gov.au
Website   www.dlg.nsw.gov.au