Chapter 9 — Soils

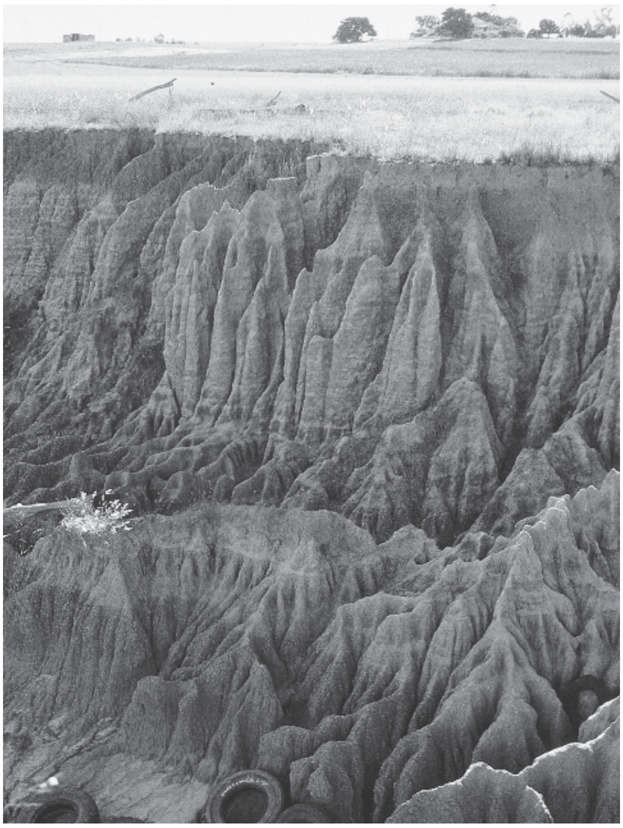
Soil properties

A soil's properties and behaviour largely determine how much water will move through the soil as deep drainage. Soil profile morphology can be a useful indicator of past salting or wetness. In Queensland, salting outbreaks commonly occur on clay soils. Duplex soils in Queensland may be associated with salting adjacent to the salted area. In Victoria and Western Australia, duplex soils figure prominently in salted areas, and contribute water to salted areas by lateral flow through the A horizon which is more permeable than the B horizon (Conacher 1975; Peck 1978).

Soil characteristics such as mottling, colour and manganese and iron distribution in the profile indicate soil wetness. Wilson (1982) undertook a detailed study of the relationship between soil morphology and high watertables in the Ingham area. From the characteristics of soil mottles (amount, size, contrast and colour) and soil colour, the number of days a watertable fluctuates in a horizon and the number of days of waterlogging could be predicted. Powell (1985) discussed this subject further.

Figure 36. Development of mottles associated with a fluctuating shallow watertable in a soil used for sugarcane in South East Queensland.

Figure 37. Gully erosion in a catchment near Mundubbera resulting from land clearing and changed hydrology.



Soil morphology is particularly useful for identifying catena landforms (characterised by changes in soil properties down a slope, see ***Landform feature identification*** page 39) where soils are the product of weathering and salinisation under past water regimes. Examples are solodic and solonised solonetz soils in lower slope positions.

Sources of information

- In addition to describing the soil directly, information on soils in particular areas can be obtained from the Department of Environment and Resource Management and CSIRO soil maps and reports.

Interpretation

As rough rules of thumb, the following soil properties and features are generally relevant to salinity.

Soil pH

Acid soils (pH < 6.5) tend to be soils with moderate to high deep drainage rates. Generally, the more acid the soil, the greater the deep drainage rate.

Neutral pH soils (6.5–7.5) are generally reasonably permeable.

Alkaline soils (pH 7.6–8.7) characteristically contain $CaCO_3$ in the profile. The equilibrium pH for $CaCO_3$ is approximately 8.4 (depending on the partial pressure of CO_2). Soils in this pH range have relatively low recharge rates unless derived from basaltic parent materials or other geological formations high in calcium.

Strongly alkaline soils (pH > 8.7) indicate the presence of sodium carbonate or sodium bicarbonate since these two carbonates dissociate into a strong alkali. High pH is often characteristic of highly sodic soils since any available calcium is usually precipitated as $CaCO_3$. The remaining sodium replaces ions on the clay exchange sites.

Concretions

Massive or numerous nodules of calcium carbonate ($CaCO_3$) at varying depths in the soil profile (but generally within the top 0.6 to 0.9 m) can indicate a historic seepage of waters with high calcium content. $CaCO_3$ precipitates out of solution on concentration or when the partial pressure of CO_2 is reduced, such as at a watertable surface (see ***Processes controlling ionic composition*** page 74). $CaCO_3$ nodules tend to occur in areas with high levels of calcium in the groundwater, such as in basalt regions.

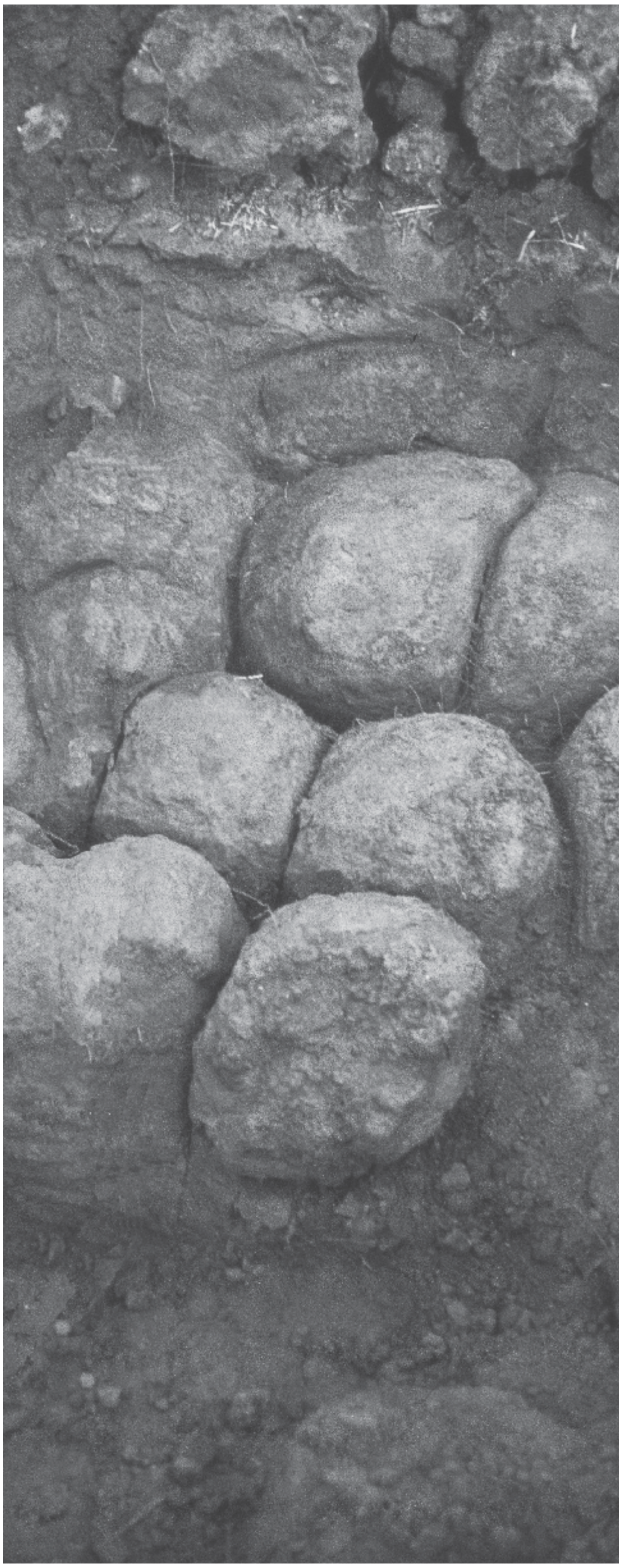
At the water–air interface in groundwaters rich in iron or manganese, oxidation results in the precipitation of iron oxides and/or manganese oxides as nodules or concretions, referred to as iron and manganese nodules. This occurs in acid soils.

Clay content and mineralogy

Cracking clay soils have variable rates of deep drainage depending on the subsoil sodicity. More sodic soils have lower deep drainage rates. Low ESP soils have higher deep drainage rates, even with very high clay content, because the soils develop good structure. Soil depth is also a factor: deeper cracking clay soils have high plant-available water capacity and low redistribution of infiltrated water, resulting in lower deep drainage than shallower soils.

Because high clay content montmorillonite soils are often low in sodium, they form well-structured, relatively permeable soils. Black earth soils with as much as 70% clay content can be quite permeable. Soils with kaolinite mineralogy are usually more permeable than soils with mixed clay mineralogy, such as kaolinite combined with montmorillonite or with illite.

Figure 38. Columnar structure of the upper B horizon of a sodic texture contrast soil at Emerald, Queensland. The formation of these characteristics, including the sandy-loam texture of the A horizon, can be attributed to the movement of dispersed clay in response to the hydrologic regime operating during soil formation.



In summary, Table 24 lists properties of soils likely to be found in possible discharge or recharge areas.

Table 24. Soil properties typical of recharge areas or current or historic discharge areas.

Soil properties	Likely indication
• mottling • gleying • manganiferous staining • numerous $CaCO_3$, silcrete, manganese or iron nodules near soil surface • fluffy soil surface • surface salts • bare wet areas with dead vegetation	permanent, periodic or historic discharge area
• mottling • gleying • indicators intensifying with depth, and soil becoming saturated with water • variable pH • moderate to high salt content in subsoils	shallow seasonal or fluctuating watertable, possible discharge area
• permeable soils (e.g. sands, lithosols, krasnozems, non-saline soils generally) • shallow soils overlying weathered or fractured rocks • weathered soils	recharge area

Soil salinity

A range of direct and indirect laboratory and field methods are used to measure soil salinity. The more common methods are listed in Table 25 (overleaf). The first two tests in the table, EC of a 1:5 soil:water suspension and saturation extract, are described in detail in ***Electrical conductivity as a measure of salinity*** (page 30). Electromagnetic induction is described in the section ***Landscape salinity mapping*** (page 43).

Techniques for measuring $EC_{1:5}$

Field method

This method is appropriate for quick field tests. Field test results will differ from laboratory results because soil drying, shaking and settling times are not standardised in the field. However, to simply identify the order of magnitude of a salinity problem, these factors can be ignored.

1. Add approximately 10 mL of distilled water, rainwater or tank water (or other water, if none of these is available) to a centrifuge tube.
2. Add small soil aggregates (to reduce breakdown time) until the contents of the tube increase by 5 mL to bring the volume to 15 mL.
3. Add additional water to bring the total volume to 30 mL.
4. Shake intermittently for 5 minutes and allow to settle for 5 minutes.
5. Dip an EC probe into the supernatant solution (rather than the sediment) and take a reading.

Note: A field test such as this provides a useful approximation of $EC_{1:5}$, and correcting for bulk density will not improve the accuracy of the reading. Since field soils are often moist to wet, any bulk density effects will be confounded by moisture content. In surface soils, bulk density is about 1 000 to 1 500 kg/m³, and in subsoils, up to 2 000 kg/m³. There are as many errors in reading the water level on the centrifuge tube as in correcting for bulk density.

Laboratory method

Soils are air dried (at 40°C) and ground (to less than 2 mm particles) and then mixed into suspension in a solution of one part soil to five parts deionised water at 25°C. After shaking for one hour and settling for one hour, the EC, pH and Cl are measured. (For a description of the Australian standard method for measuring EC at saturation, refer to Rayment and Higginson 1992.)

Interpretation and classification

A range of soil salinity criteria is currently used in Queensland and worldwide. A number of these criteria are specific to the areas in which they were developed, so their application to Queensland conditions is limited. Most of these criteria were developed to provide rough practical guidelines for interpreting soil salinity data. Most soil processes and values occur on a continuum, so criteria which suggest sharp class boundaries should be applied with some flexibility. The more commonly used criteria are listed in Table 26.

Shaw et al. (1987) developed a salinity classification system based on plant salt tolerance, using a 10% yield reduction value instead of the zero yield reduction of the Maas and Hoffman (1977) revision of the USSL (1954) scheme. Shaw et al. (1987) added an additional 'very low' salinity level for salt-sensitive horticultural tree crops (Table 27). $EC_{1:5}$ ranges were derived for different clay contents which would be equivalent to the EC_{se} soil salinity levels for each of the plant salt-tolerance groupings based on clay content and chloride concentration.

Table 25. Common methods for measuring salinity in soils.

Method	Lab or field	Advantages	Disadvantages/limitations	Use
1:5 soil water suspension	lab or field	fast, routine	too dilute, particularly in sandy soils (up to 40 times more dilute than field water contents); sparingly soluble salts cause problems of over-estimation of salinity	fast field and lab survey
Saturation extract	lab	closer to field water content— 2 to 3 times more dilute	tedious preparation	quantitative evaluation of salinity, comparison across soils
Electromagnetic induction	field	very fast	non-linear depth integration; soil properties and water content have some effect	initial broad area survey
Time domain reflectometry	lab and field	measures soil EC at field water content, also measures field water content	expensive; technique not yet sufficiently tested problems with signal strength in high CEC, soils; not as good for salt as for water content	research, monitoring
Soil solution extraction	field	measures soil EC at field water content	tedious preparation; not for heavy clay soils degassed sample; high spatial variability;	research for evaluating leaching and deep drainage, monitoring
Soil solution displacement	lab	accurate at field water content	very tedious; poor solution yield	research
Ceramic salinity sensors	field	measure soil EC at field water content	very slow response; drift in calibration	research, monitoring

Table 26. Soil salinity criteria in common use.

Assessment scheme	Comment
USSL (1954)	These are universally applied criteria using plant salt tolerance as the basis, and are well respected. Maas & Hoffman (1977) revised these criteria with small changes. The salinity categories apply if ECse reaches the specified level anywhere in the root zone. This makes the criteria too conservative for Australian soils which have generally lower permeabilities than USA soils with consequent high salt accumulation at depth.
Northcote & Skene (1972)	These criteria are based on the Cl content of a 1:5 soil:water suspension, approximating an EC_{se} of 4 dS/m of USSL (1954) above. Northcote & Skene attempted to make the values more relevant to Australian soils by considering texture and incorporating a depth term. Values are only considered to a depth of 1 m and maximum values within this depth are taken to be diagnostic. Chloride alone will provide an underestimate of salinity if gypsum or sodium carbonates are present.
Bruce & Rayment (1982)	These criteria do not relate particularly well to either of the above schemes and have Cl levels lower than is normally encountered for the corresponding EC categories. These criteria are being revised.

The soil salinity rating is a description of the soil salinity level which would correspond to the various plant salt-tolerance groupings.

The Maas and Hoffman (1977) plant salt tolerance criteria are based on average root zone salinity for plants grown under high leaching fractions. The criteria in Table 27 can be used as the soil salinity level at which plants respond to salinity with the specified groups of Maas and Hoffman, either as average root zone salinity or as water uptake weighted salinity (discussed in further detail in ***Root zone salinity*** page 34).

These relationships and criteria have been incorporated into the SALFPREDICT component of the SALF software package, which can be used to predict soil leaching fraction resulting from variations in applied water quantity and quality, root zone salinity, yield decline for nominated crops, deep drainage loss and deep drainage salinity. (This package is described in ***Useful software packages*** page 141.)

Soil salt profiles

An examination of salt profile shapes to a depth of, say, 1.5 m to 2 m is a fast and simple method of determining the hydrologic processes that may be occurring in a specific location in a catchment.

Table 27. Soil salinity criteria EC_{se}, and $EC_{1:5}$ for four ranges of soil clay content (adapted from Shaw et al. 1987).

Plant salt-tolerance grouping[1]	Corresponding ECse range[2] (dS/m)	Equivalent EC1:5 reading, based on clay content of soil (dS/m)				Soil salinity rating
		10–20% clay	20–40% clay	40–60% clay	60–80% clay	
Sensitive crops	< 0.95	< 0.07	< 0.09	< 0.12	< 0.15	very low
Moderately sensitive crops	0.95–1.9	0.07–0.15	0.09–0.19	0.12–0.24	0.15–0.3	low
Moderately tolerant crops	1.9–4.5	0.15–0.34	0.19–0.45	0.24–0.56	0.3–0.7	medium
Tolerant crops	4.5–7.7	0.34–0.63	0.45–0.76	0.56–0.96	0.7–1.18	high
Very tolerant crops	7.7–12.2	0.63–0.93	0.76–1.21	0.96–1.53	1.18–1.87	very high
Generally too saline for crops	> 12.2	> 0.93	> 1.21	> 1.53	> 1.87	extreme

1. These groupings are statistically derived divisions based on families of linear curves representing the salt-tolerance ratings of the majority of crops reported by Maas and Hoffman (1977). The terminology of Maas and Hoffman has been modified and an additional group of sensitive crops incorporated.
2. EC_{se} given here is the boundary EC_{se} at which 10% yield reduction occurs for these plant salt tolerance groups. The $EC_{1:5}$ ranges have been determined from these EC_{se} ranges using the equations provided in *Converting from $EC_{1:5}$ to EC_{se} (page 30)*.

Based on long-term steady state conditions, the mass of salt in a soil profile will be in equilibrium with the amount of salt entering the soil profile via rainfall and weathering and the amount of salt leaving the soil profile via deep drainage (and a small amount in plant uptake).

Since the salt content at any depth in the soil profile can be related to the relative rates of evapotranspiration and soil hydraulic conductivity, the salt profile shape will reflect the hydrology of the soil.

Sources of information

- In addition to conducting soil salinity tests in the target area, soil survey reports are generally available from the Department of Environment and Resource Management.

Interpretation

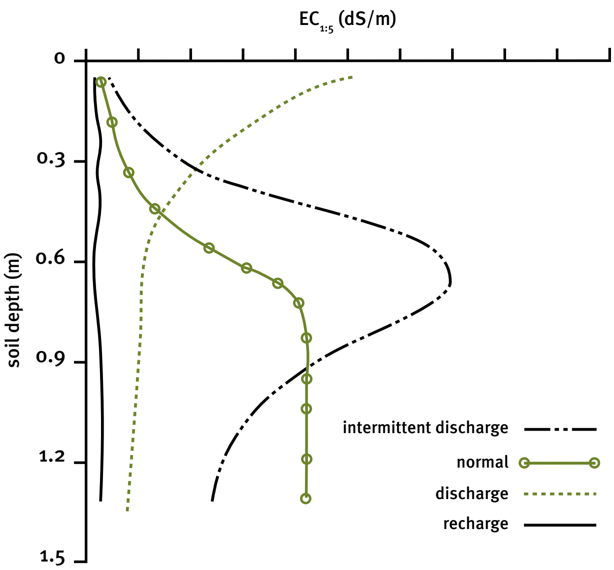
Figure 39 illustrates typical salt profile shapes associated with recharge, discharge, normal and intermittent recharge-discharge areas.

The **recharge** profile in Figure 39 is indicative of a soil with high hydraulic conductivity and seasonal or annual flushing of the small amounts of salt that accumulate as a result of evapotranspiration.

In the **normal** profile, the soil hydraulic conductivity is low and plants utilise more of the water in the soil profile, leaving salts behind. The depth in the root zone below which salt concentration is essentially constant represents the depth at which the roots are not taking up water. Over long time periods, each small pulse of salt in the recharge water builds up the general shape of the profile. The depth to the point of constant concentration varies with soil properties and the quantity of rainfall as well as the rooting depth of the vegetation. Thus, some soils that also show reasonable recharge may have a normal soil salt profile shape, but at a relatively low concentration.

The **discharge** profile is indicative of evaporation of water brought to the soil surface from a shallow watertable by capillary rise. In the other profiles described above, the dominant source of water is from the soil surface as rainfall. In this profile, the salt concentration at depth in the soil profile reflects the saline concentration of the shallow watertable. The degree of salt concentration at the soil surface will depend on rainfall, leaching and surface salt flushing.

Figure 39. Typical salt profile shapes associated with recharge, discharge, normal and intermittent areas.



In a soil represented by the **intermittent** profile, the watertable may have fluctuated over a number of years from being shallow enough to result in salt concentration due to capillary rise, to deeper depths where capillary rise is so low that it is essentially zero. In this case, the salt concentration is moved downwards by rainfall and upwards with the intermittent watertable rises, resulting in a fairly pronounced peak. This profile can also indicate bypass flow, where the soil is structured with macropores, allowing water to bypass the matrix into a better structured soil below the root zone.

Soil sodicity

The two most common measures of soil sodicity are:

- exchangeable sodium percentage (ESP), being the proportion of sodium adsorbed onto the clay mineral surfaces as a proportion of total cation exchange capacity
- sodium adsorption ratio (SAR), being the relative concentration of sodium to calcium and magnesium in the soil solution.

Measures of sodicity are explained in detail in ***Sodicity in soils and waters*** (page 37).

Sources of information

- Chemical analyses of soil samples and soil survey results and reports are the primary sources of information.

Interpretation and classification

As for soil salinity criteria (discussed in Soil salinity page 60), many of the criteria developed for categorising soil sodicity were developed for average situations in specific areas. As a result, these criteria are not definitive. Northcote and Skene (1972) devised criteria that are useful for Australian soils (Table 28). However, these criteria need to be considered in relation to soil properties, because the influence of sodicity on soil behaviour varies with clay content and clay mineralogy (Shaw & Thorburn 1985a). In higher clay content soils, lower ESP levels have a significant effect on soil structure.

Table 28. Criteria for classifying sodicity in soils (from Northcote & Skene 1972).

Criteria	Description
ESP ‹ 6	non-sodic
ESP 6–14	sodic
ESP › 15	strongly sodic

Soils of 30% to 50% clay with mixed mineralogy are most sensitive to ESP. In surface soils unprotected by crop cover or mulch (and therefore subject to rainfall energy), an ESP value of 3 is possibly a more accurate measure of 'non-sodic'. For silty soils in Israel, for example, a surface ESP of only 1 to 1.5 will contribute to soil crusting and reduced infiltration. This is not as severe a problem for Australian soils. An ESP of 15 or greater can be tolerated at subsoil depths, particularly if the soil is a cracking clay soil.

The sodicity criteria given in Table 28 are not fixed values to be rigidly applied to all soils. Sands will tolerate much higher ESP values than clay soils. This is illustrated in Figure 40, which shows the soil EC_{se} required to maintain a soil structure for two soils of different soil texture and various soil ESP levels. The figure is based on an annual rainfall of 1000 mm/year.

Figure 40. The threshold lines for two soils of different clay content and mineralogy for an annual rainfall of 1000 mm/y. The soils are unstable in the areas to the left of the lines and increasingly stable to the right of the lines.

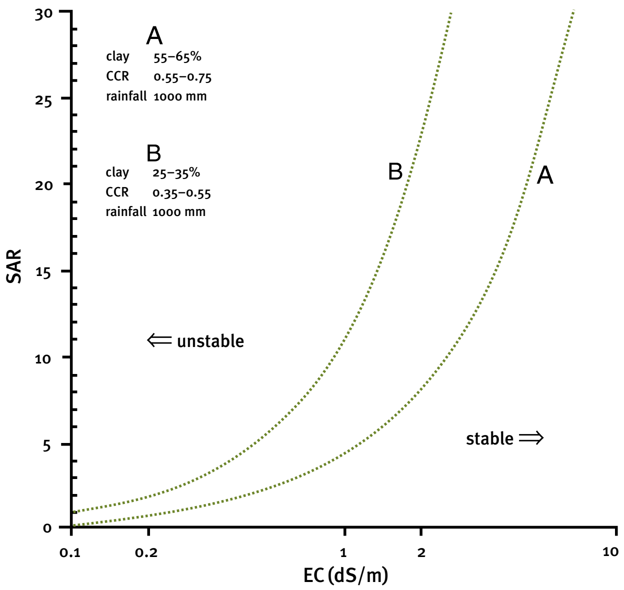
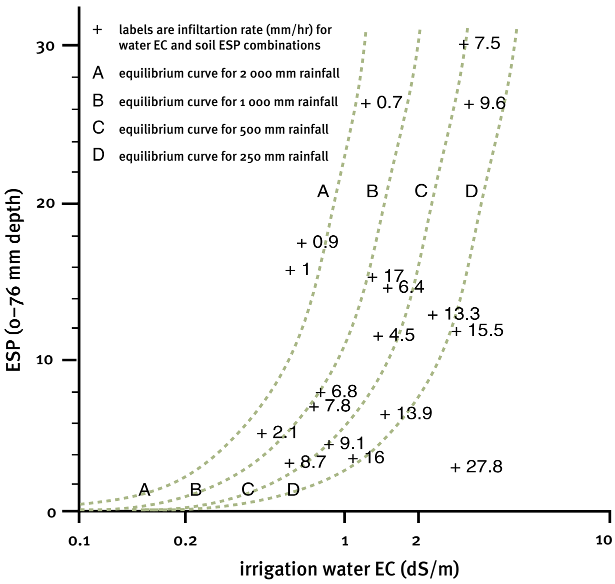


Figure 41. Infiltration rates for soil surface of cores of Oster and Schroer (1979) and equilibrium lines for soil properties at four rainfalls (after Shaw 1996).



The effect of the combination of EC and ESP on hydraulic conductivity is shown in Figure 41. Oster and Schroer (1979) evaluated the infiltration rate of various water qualities on cropped, 0.2 m diameter, 0.53 m long undisturbed soil cores.

Infiltration rates were assessed after 19 months. The ESP of the 0–76 mm soil depth is plotted against the EC of the irrigation water in Figure 41. The threshold equilibrium lines at rainfalls of 250, 500, 1 000 and 2 000 mm/year from Shaw (1996) are also shown in the figure.

The labels are the infiltration rate (mm/hr) for the irrigation water EC and soil ESP of the 0–76 mm depth of the soil columns. These data illustrate that there is no predefined threshold value of ESP above which soil permeability dramatically decreases. The equilibrium lines are similar to the hydraulic conductivity values, indicating the interdependence and effect of EC and ESP in maintaining the hydraulic conductivity of soils.