# INTERRELATIONSHIPS BETWEEN SALT CONTENT, WATER CONTENT AND WATER POTENTIAL IN AN EXPANSIVE CLAY SOIL

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This work was conducted in the Department of Botany, University of Queensland as part of PhD thesis submitted in 1973. The initial lack of an explanation for the mechanism prevented prior publication.

## Abstract

The relationships between water content and water potential of clay soil samples with different salt contents were determined using a thermocouple psychrometer. The observed relationships did not match those predicted when assuming that either all soil water was osmotically active or that the water was separated equipotentially between the osmotic and matric phases. The results show a partitioning of water between osmotically active and inactive phases and that the volume of the latter phase remains constant at 7.6% soil water content. This partitioning of water increases the osmotic effect of salt compared to that normally predicted, particularly at low soil water contents.

## Introduction

Salt in soil produces an osmotic effect that contributes to total soil water potential. The effect of salt on the retention of water in expansive clays has been discussed by Richards (1980) who concluded that total soil water potential could be defined and measured but that its partitioning in such clays into matric and solute components was arbitrary. In clay soils there are anomalous effects which have been explained in terms of the structuring of water in close proximity to clay surfaces (Low 1961).

With negative absorption every wet clay surface will have associated with it a region from which anions are excluded. This is a requirement for salt sieving by clay soil aggregates (Blackmore 1976) and was proposed as an explanation for an apparent increase in concentration of salt solutions when added to dry clay soils (Oster et al. 1969). Observation of such effects led to the development of the concept of bound or solute free water (Rode 1969). This study investigates the applicability of this concept by evaluating the contribution of osmotic potential to total water potential of an expansive clay. The objective was to evaluate the effect of salt on water availability to plants in a clay soil.

## Methods

The experimental site and the techniques used in the field and for soil chemical analysis are given by Tunstall and Connor 1975, 1981. The soil is a deep gilgaied expansive clay (Isbell 1957, 1962) classified as Ug 5.24 (Northcote 1979). The clay content of the soil is approximately 60% of which the proportions of montmorillonite and kaolinite are approximately 40% and 50% respectively. Samples were obtained from 20 bore holes drilled for neutron moisture meter access which ranged in depth from 2 to 5m. Soil moisture characteristics were determined on twelve separate soil samples of which six came from a single bore hole. The remainder came from four other holes and were chosen to encompass the range of salt contents encountered.

Air dried soil samples were ground to pass a 2 mm sieve and chemical measurements were obtained on 1:5 soil water suspensions. Specific conductivity was measured using a resistance bridge, and chloride by potentiometric titration with mercuric nitrate.

Total soil water potential was measured in the laboratory using a 4 terminal peltier-effect thermocouple psychrometer (Miller et al. 1970) operated at 35ºC. At this temperature the psychrometer covered the required range of water potential. Approximately 1.7 g of soil was placed in a psychometer chamber and thoroughly mixed with the amount of water required to achieve the desired water content. The chamber was sealed and let stand for 12 hours at 25ºC before being placed on the thermocouple unit. Readings were taken after equilibration in a constant temperature bath. A total equilibration period of 12 h was found to be sufficient but for convenience a 24 h cycle was adopted. The water content of each sample was determined gravimetrically after removal from the bath.

All percentages are gravimetric referenced to the dry weight of soil.

## Results and Discussion

The regression between chloride and specific conductivity was:

chloride = -0.0161 + 0.16 x specific conductivity (n = 85, $R^2$ = 0.98).

Chloride in g/100 g

Specific conductivity in mS $cm^{-1}$

Comparison of this regression with measurements of specific conductivity of NaC1 solutions (USDA 1950) indicates that chloride, as sodium chloride, accounts for the observed specific conductivities. Sodium and chloride are the dominant ions in the soil, particularly at depth (Russell et al. 1967).

The relationships between water content and water potential of the six samples from the one bore hole are shown in Fig. 1. The curves were fitted by eye. Results for the other six samples were similar.

The effect of salt on:

a. soil water content at different soil water potentials, and
b. soil water potential at different soil water contents,

are illustrated in Figs. 2 and 3 respectively. The values in these figures were derived from the smooth curves drawn through the experimentally determined points of water potential : water content illustrated in Fig. 1. The linear regressions for all relationships in Figs 2 and 3 were significant.

The osmotic component of soil water potential is zero at zero salt content by definition. The intercepts of the linear regressions in Fig. 2 therefore allow construction of an idealized matric potential- water content curve (Fig. 4, curve a) that represents an average for all soil samples. The relationship between water content and the idealized matric potential differs little from that obtained for the soil sample of lowest salt content given in Fig. 1.

The classical analysis of Taylor and Slatyer (1960) assumes that matric and osmotic potentials are simple partial free energies and so are additive as shown in equation (1). Such a system functions as if the water is equally available to the matric and osmotic phases.

$$\psi_T = \psi_m + \psi_S \quad (1)$$

where $\psi_T$ is the total water potential as measured by thermocouple psychrometer

$\psi_m$ is the matric component

$\psi_s$ is the solute or osmotic component .

In systems with semi-permeable membranes it is possible for the osmotic component to be sequestered and an equation similar to (2) is then applicable (Acock 1975), although there are usually other potentials as well. Such a system functions as though the water is partitioned between the matric and osmotic phases

$$\psi_T = \psi_m = \psi_S \quad (2)$$

Curve (b) in Fig. 4 shows the measured water content - water potential relationship for a soil sample of 0.6% NaC1. For comparison with this curve theoretical curves were derived by adding the matric potential (Fig. 4 curve a) to the osmotic potential calculated according to:

- Equation (1) (Fig. 4 curve c)
- Equation (2) (Fig. 4 curve d).

Osmotic potentials for NaC1 at 35ºC were obtained from Lang (1967).

Where water is equally available to both phases (Equation 1) the solution concentration is proportional to salt content and inversely proportional to soil water content. Where water is partitioned between the phases but can move between them (Equation 2) the relationship between total potential and water content is derived by summing the water contained in the matric and osmotic phases at given potentials.

Neither theoretical curve in Fig. 4 matches observation. At high water potentials the single phase model is most applicable while at low water potential the double phase model agrees best with observation.

To evaluate the relationship between soil water, salt content and the amount of osmotically active water it was assumed that the slopes of the regressions in Fig. 3 define the increase in osmotic potential with increase in salt content. The ratios of these observed values to those predicted assuming a single phase system (one in which all water is osmotically active) are presented in Table 1. The effect of salt was greater than predicted. The reciprocal of this ratio indicates the proportion of the soil water that is osmotically active, so by difference the osmotically inactive water can be computed. This non-solvent volume of soil moisture was independent of soil water content and averaged 7.6 + - 0.6% (Table 1).

**Table 1.** Amount of osmotically inactive water at different soil water contents.

| **Soil water content (%)** | **Osmotically inactive water (%)** |
|---|---|
| 14 | 7.5 |
| 16 | 7.4 |
| 18 | 7.9 |
| 20 | 8.6 |
| 22 | 6.9 |
| 24 | 7.2 |

Alternative explanations to the observed results can be considered. Soil salt contents may have been underestimated. However, with error in salt determination the ratio of observed to calculated osmotic potentials would be independent of water content. They would not vary as in Table 1. The effect of error in salt determination is illustrated in Fig. 5 curve (b) by combining the predicted matric potential (Fig. 4 curve a) with osmotic potential for a sample of 1.2% salt content computed assuming a single phase system. The results cannot be explained by errors in the estimation of salt.

Grinding the soil is of little consequence because over the measured range of water potentials little water is held in capillaries. However, the analysis assumes an average soil structure by way of clay content. Soil salt content increased with depth in the soil profile and clay content would also be expected to show some increase with depth (Isbell 1962).

Increase in either salt or clay may similarly alter the relationship between soil water potential and water content. The observed ‘anomalous’ effects of salt could therefore possibly arise through the clay content increasing in association with salt content. This possibility was explored by examining the relationship between matric potential and water content for a soil sample of 0.6% salt content, derived from the measured total water potential curve assuming all water to be osmotically active. This relationship (Fig. 5, curve c) shows a maximum water content at -3.0 MPa. This result is highly anomalous and cannot be due to variation in clay content. The results cannot be explained in terms of variation in soil clay content.

The relationships illustrated in Fig.1 were used to convert field measures of soil water and salt contents to soil water potential. Although soil water content profiles were markedly curvilinear the soil water potential profiles tended to be uniform, particularly in a drying soil (Tunstall and Connor 1981). The soil water potential at depth was consistently around -3.5 MPa and water was extracted from these regions only when plant water potentials were more negative (Tunstall and Connor, 1981). This concurrence between laboratory and field measurements indicates that the laboratory measurements are reliable. It also illustrates that the osmotic effect of salt is important in the growth relations of plants.

Recent observations have identified the existence of two structural forms for liquid water (Chaplin, 2005). The different structural states react differently to different ions thereby producing osmotic and pressure gradients in systems having neutral and charged surfaces, such as clays (Wiggins 2004). This separation of ions increases the osmotic potential compared to that expected with uniform distribution of ions and the magnitude of this effect increases with increasing salt concentration.

## Conclusions

The results indicate the assumption that the matric and osmotic potentials in clay soils are additive is invalid. The realised osmotic potential is greater than that predicted assuming simple partial free energies and increases with increasing salt concentration. It therefore increases as soils become dry. The osmotic reduction in water availability to plants is greater than normally calculated, particularly in a drying soil.

The magnitude of the increase in the osmotic potential compared to additive partial free energies equates with an amount of soil water being unavailable for the dissolution of salts. This non-solvent volume of soil water averaged 7.6% and was independent of both soil salt and water contents.

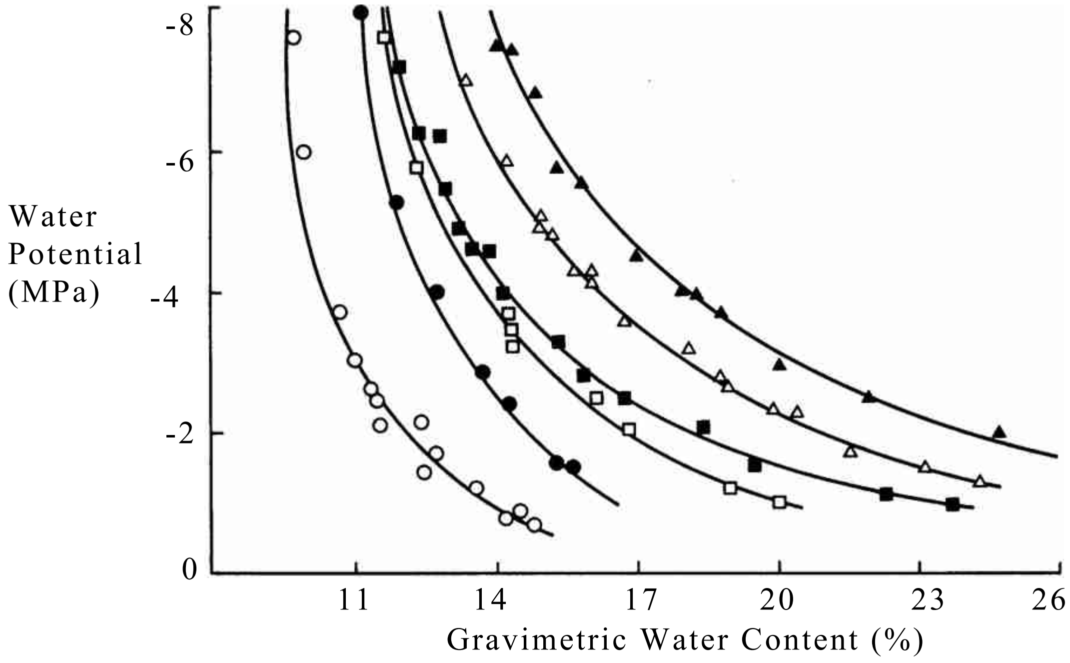

**Fig. 1** Water content – water potential characteristics for soil samples from different depths in the one bore hole.

Sample depths (m) and salinities (mS/cm) were: 0.1m - 0.15, 0.3m - 1.0, 0.6m - 1.3, 1.2m - 1.63, 2.1m -1.95, 3.0m - 2.12

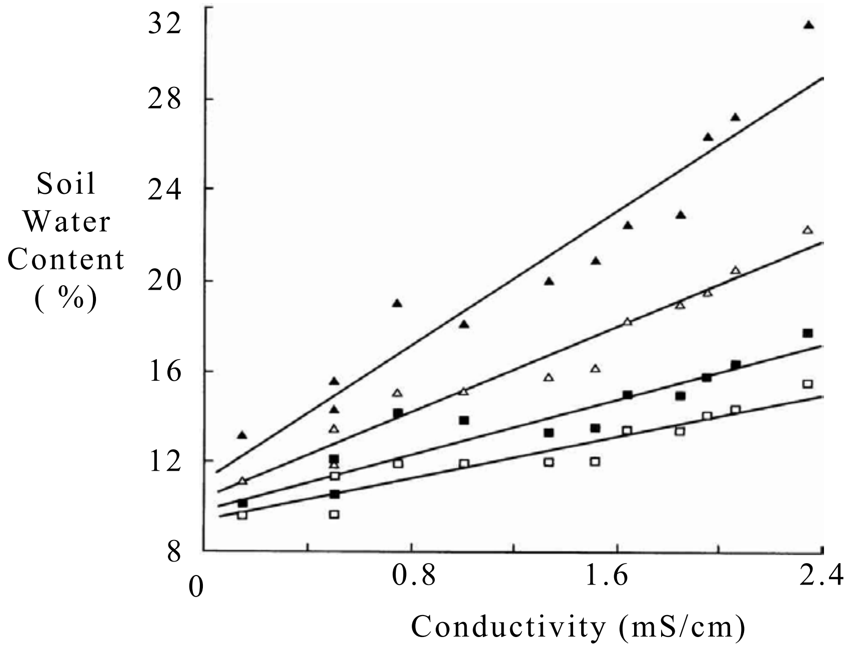

**Fig. 2** Relationship between soil salt content and soil water content at different soil water potentials.

▲ -1.5 MPa   Δ -3.0 MPa   ■ -5.0 MPa   □ -7.0 MPa

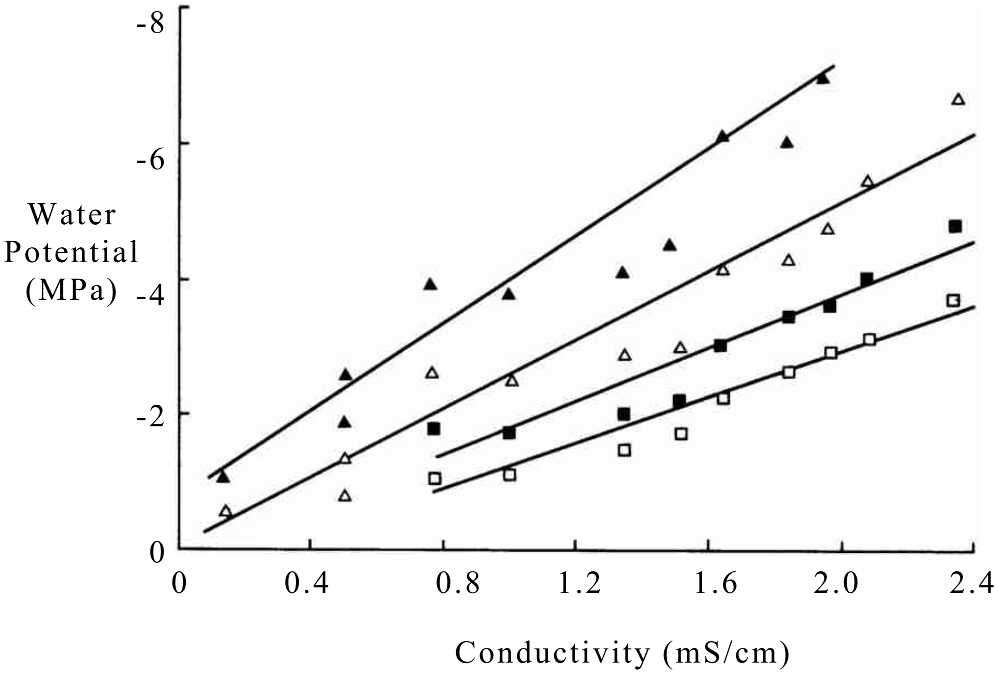

**Fig. 3**. Relationship between salt content and total soil water potential at different soil water contents

Soil Water Content ▲ 14%, Δ 16% , ■ 18% , □ 20%

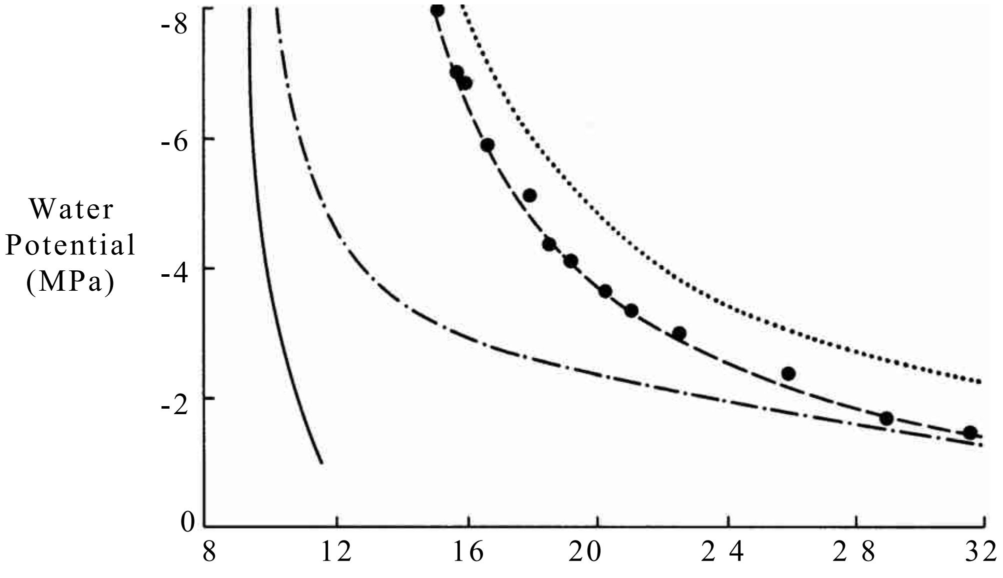

**Fig. 4**. Soil water content – water potential characteristics for soil samples with:

**a** Zero salt content (from the Y intercepts of the regressions in Fig. 2).
**b** 0.6% salt content as determined experimentally.
**c** 0.6% salt content as calculated for a single phase system.
**d** 0.6% salt content as calculated for a two phase system.

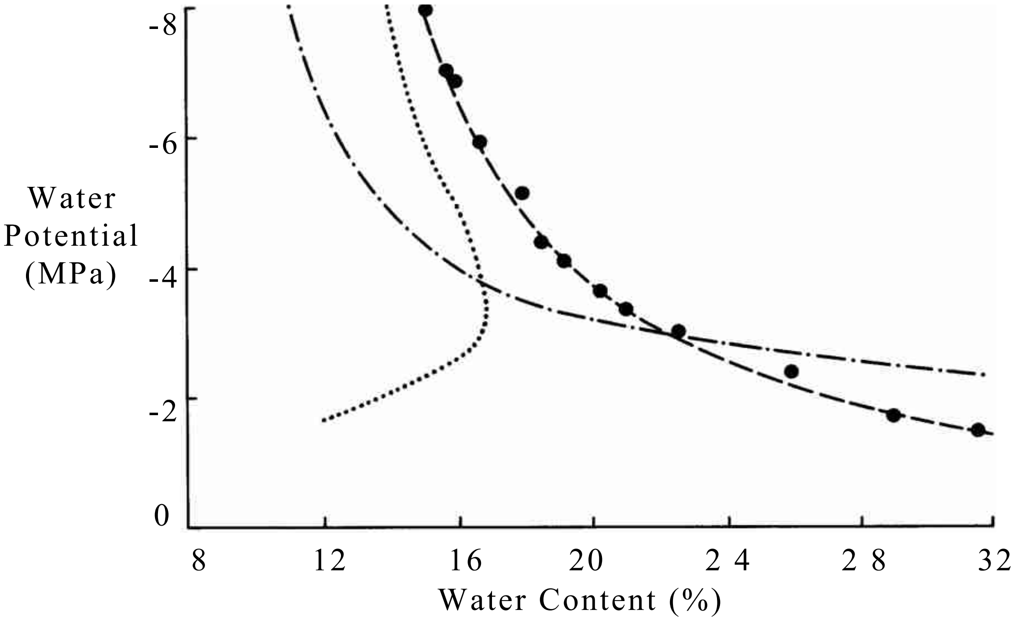

**Fig. 5** Soil water content – water potential characteristics for a soil sample with:

**a** 0.6% salt content as determined experimentally (curve (b) in Fig. 4).

**b** 1.2% salt content calculated for a single phase system (adding the calculated osmotic potential to curve (a) in Fig 4).

**c** Matric potential derived from measured total potential for a soil with 0.6% salt by subtracting the osmotic potential calculated assuming a single phase system.

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