

SPATIAL INTERACTIONS OF SODICITY, SALINITY AND CA:Mg RATIO TO DETERMINE SOIL STRUCTURAL DEGRADATION UNDER IRRIGATED COTTON

Inakwu O.A. Odeh^A and Alex. Onus
Australian Cotton Cooperative Research Centre,
School of Land, Water and Crop Sciences,
The University of Sydney, NSW 2006

^ACorresponding Author; Email: i.odeh@acss.usyd.edu.au

Abstract

The Bourke region has experienced a dramatic expansion of irrigated agriculture, especially cotton production, over the last decade. For sustainable agricultural production, quantitative soil information is required for effective land management and environmental planning. There is therefore the need for updating the soil resource information of the region. Soil sodicity and structural stability are two soil quality indicators specifically investigated in this study. The study is aimed to assess the current levels of soil sodicity and aggregate stability in order to predict spatial patterns of these soil attributes with the view of identifying the risk zones. The effect of land use on the soil quality indicators is examined.

Geographical information system (GIS) and geostatistical techniques— primarily regression-kriging and indicator kriging, were used to spatially predict the soil sodicity and other structural stability indicators. Areas of high risk of potential ($ESP > 6$) were identified. It was established that the incorporation of EC with ESP into an objective index called electrolyte stability index (ESI) gave the best indication of soil dispersion, a measure of potential soil structural degradation. Ca:Mg is a poor predictor of potential clay dispersion.

Keywords: Bourke, cotton, soil sodicity, soil structure, spatial prediction, Ca:Mg, remote sensing, GIS.

Introduction

The dramatic expansion of irrigated-cotton production in the Bourke region over the last decade has significantly increased the importance of quantitative soil quality information for the region. As an important resource for cotton production, soils and their conditions, as typified by their quality indicators, should be monitored to ascertain their effects of actual and potential agricultural production.

Sodic soils are a major threat to agriculture in much of the arable land of Australia. In sodic soils, large amounts of sodium attached to clay surfaces increase the likelihood of clay dispersion upon addition of water. Soil dispersion may produce massive structure in which root penetration and seedling establishment is poor and air and water movement is restricted (Dougherty and Anderson, 2001). Crop growth can be adversely affected due to the resulting poor physical condition and the difficulty of managing it. Soil sodification is especially relevant to the Bourke region as poor management of irrigated cotton production may accentuate the current levels of sodicity. However, the effect of sodicity on soil structural stability is tampered by other factors such as salinity and Ca:Mg ratio. This paper explores the

interactions of these soil quality indicators as they influence soil structural degradation. Remote sensing and geographical information system (GIS) tools were utilized in data analysis and to display simulated maps and results.

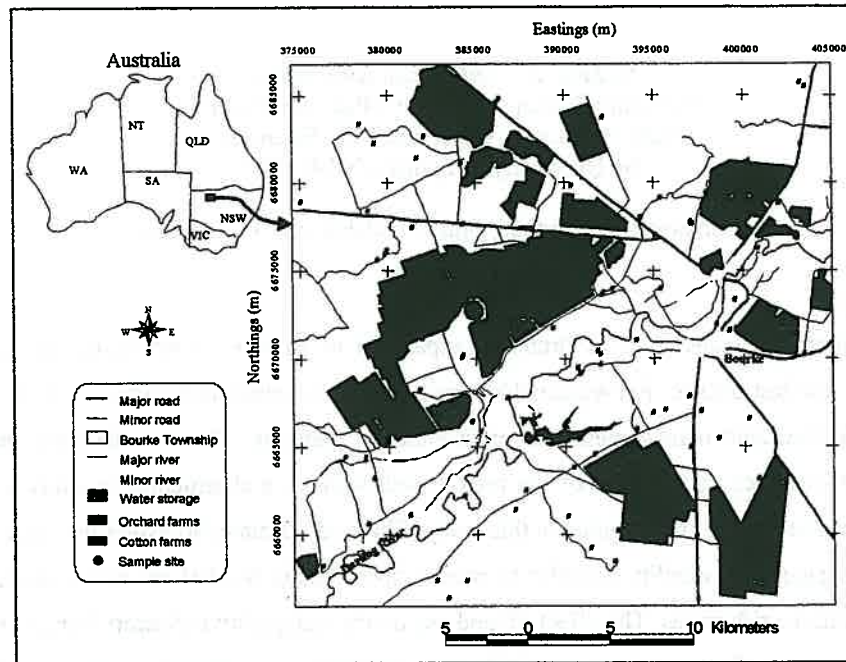


Figure 1. The Bourke study area, showing the sample sites and land use

Materials and methods

The Study Area

The study area- an 90 km² around Bourke, is approximately 700 km northwest of Sydney, Australia (Figure 1). The area is dominated by Vertosols (Isbell, 1996). However, there are also significant areas of Kandosols and Sodosols (CSIRO, 2001). The region is part of the Eromanga Basin, which is characterised by large expanses of low relief and extensive alluvial systems. Gypsic horizons are found at depth in some of the grey clayey alluvial soils (Vertosols) and the sandy red soils (Kandosols). The A horizon of most of the Vertosols is characterized by diffuse carbonates, while nodular carbonates are more preponderant in the Kandosols. Gypsum and carbonates are most probably of aeolian origin (Warr *et al.*, 2001).

The Bourke region has a predominantly summer rainfall. The annual average for Bourke Town is 355 mm, which is relatively low for NSW. The region is so arid that agriculture has to rely on irrigation for the production of such crops as cotton, peanuts and orchards. The number of rainy days per month remains generally even throughout the year, suggesting more intense rainfall during summer months. Irrigated agriculture is mostly restricted to the low-lying alluvial plains, which have been extensively cleared. As a result, native vegetation is restricted to areas adjacent to the Darling River and higher (more) sandy levees, which are of lesser agricultural importance. Within the last 10 years irrigated-cotton production has expanded dramatically, especially on the low-relief alluvial plains. Recent agricultural developments in the area include vineyards and orchards, producing melons and citrus (Figure 1).

Field sampling and soil data

Prior to field sampling, the 30 km x 30 km study area was divided into quadrants. Within each quadrant an equal number of 25 sampling sites were randomly selected (Figure 1). The sampling density is approximately 0.156 sample per km² (Warr *et al.*, 2001). The predetermined site positions were approximately located in the field using a Global Positioning System. A 1.5 m cores was taken at each of the 100 sites using a drill rig. Paired cores were taken at randomly selected 25 sample sites out of the 100, each pair set at some 500 to 800 m apart. Samples were taken from the core at the intervals: 0-20 cm, 30-40 cm, 70-80 cm and 90-100 cm (Only the samples from 0—20 cm depth were used in this study). Additionally at each sample site the soil and surrounds were described, including land use, vegetation, landscape position, soil dominant colour, and nodules and concretions.

The exchangeable bases (Ca²⁺, Mg²⁺, Na⁺ and K⁺) were determined using the method of Tucker & Beatty (1974). The effective cation exchange capacity (CEC) was calculated by summation of the basic exchangeable cations. Exchangeable Sodium Percentage (ESP) was calculated from the ECEC using the expression:

$$ESP = \frac{[Na^+]}{ECEC} \times 100 \quad (1)$$

While in the Australian Soil Classification (Isbell, 1996) the threshold ESP for sodic soils (Sodosols) is set to 6, in SOILpak for cotton growers (McKenzie, 1998) the threshold ESP value for sodic soils is set to be >5.

Electrical conductivity (EC) was measured in a 1:5 soil: water suspension using a conductivity meter after calibration with a KCl reference solution at a given temperature. The EC values are a measure of concentration of soluble salts in the soils, which predominantly are made up of the cations: Na⁺, Mg²⁺ and Ca²⁺; and the anions Cl⁻, SO₄²⁻ and HCO₃⁻ (Rayment and Higginson, 1992). At low EC, the potential for the soil to disperse increases (McKenzie, 1998). In an attempt to incorporate this interaction into soil structural satiability indicator, electrochemical stability index (ESI) is calculated combining ESP and EC as:

$$ESI = \frac{EC}{ESP} \quad (2)$$

A potentially dispersive soil should have an ESI value less than 0.05 (McKenzie, 1998).

Another soil quality indicator which has been purported to influence soil structural stability if the Ca:Mg of the exchange complex. A Ca:Mg ratio of less than 2 is indicative of potential clay dispersion (McKenzie, 1998).

Aggregate Stability in WATER (ASWAT) test. The ASWAT test was carried out as described by Field *et al.* (1997). Air-dried aggregates taken from each sample were placed in a dish containing deionised water. At 10 minutes and 2 hours a visual assessment of the aggregate dispersion (degree of structural stability) was made on a scale of 0-4. A score of 0 indicates no dispersion; a score of 1 means slight dispersion— recognised by a slight milkiness of water adjacent to the aggregate. While a score of 2 indicates moderate dispersion with obvious milkiness, a score of 3 signifies strong dispersion with considerable milkiness with about half the original volume dispersed outwards. A score of 4 implies

complete dispersion, leaving only sand grains in a cloud of clay. For those aggregates that dispersed in the first instance, the scores for the 10 minutes and 2 hours assessment were added together to give a possible range of 0-8. For those aggregates that did not disperse, soil samples were remolded at water content just above the soil plastic limit. Remolded samples are likewise placed in deionised water and the same visual assessments made at 10 minutes and 2 hours. These scores were likewise added together, giving a range of values for the remolded samples of 0-8. The final scores for the air-dried samples are obtained by adding 8 to the summation of the scores in 10 minutes and 2 hours, thus giving a possible range of 9-16. ASWAT scores are grouped, as shown in Table 1, to indicate the severity of dispersion according to this structural diagnosis.

Spatial analysis

Regression-kriging is a hybrid geostatistical method that combines a form of regression model with ordinary kriging of the regression residuals (Odeh *et al.*, 1995). In this study, multiple-linear regression (MLR) models were first used to derive soil relationships between soil quality indicators and ancillary variables. The MLR formulas were then used to predict indicators on to the 100 m grid matrices using the ancillary variables, which are available at all of the grid nodes. The model or regression residuals were therefore spatially interpolated using the technique of ordinary kriging onto the same 100 m grid nodes. The summation of the kriged residuals to the MLR predicted values produced the final predicted values of the soil variables over the entire grid nodes. The regression-kriging method was used to spatially predict those soil quality indicators with significant relationships with the ancillary variables, namely: EC, ESP and ESI.

Indicator-kriging is a non-linear form of ordinary kriging where the original variable is transformed into an indicator variable. In this study indicator-kriging was utilized to spatially predict ASWAT values of scores between 0 and 16. As the scores are not continuous data but rather more categorical (Field *et al.*, 1997), diagnostic classification provides better information on the degree of dispersion than the raw data. Critical limits of the ASWAT score (>2 and >6) were applied to diagnose the structural stability into the following classes: stable, moderately dispersive and spontaneously dispersive (see Table 1). The likelihood of a soil sample being in each of these classes was spatially predicted using the indicator-kriging technique.

Geographical information systems (GIS) have been used for representing, visualising, synthesising and integrating spatial and thematic data. Digital maps of soil attributes, as interpolated onto the 100 m grid, were imported into Arc/Info and ArcView GIS (ESRI, 2001). GIS map queries were used to manipulate map layers. GIS map queries allow for the digital maps of soil attributes to be transformed or combined or manipulated and thus generating additional useful information. In this study these queries were particularly useful for deciphering the spatial coincidence of ESP, ESI, Ca:Mg ratio, and the indicator-kriged ASWAT test values. The queries were used to infer more useful information regarding a set of soil quality and to highlight problems areas.

Results and Discussion

Severity of dispersion	ASWAT score 'critical limits'
Structurally stable	0 - 1
Moderate dispersion	2 - 6
Spontaneous dispersion	7 - 16

Table 1 Response to the structural stability diagnosis

However, as previously stated the use of ESP as the primary soil structural stability indicator becomes more complex when, in certain conditions, it does not consistently relate to the aggregate stability and dispersion exhibited by the soils. Electrolyte concentration and Ca:Mg ratio of the exchangeable complex are the other factors that have been well documented as impeding the impact of ESP on soil dispersion (Rengasamy & Sumner, 1998). It was further proposed that if a given soil type can maintain a high electrolyte concentration ($EC_{1:5}$) and a thresholds of Ca:Mg ratio (< 2) at high level of ESP, then a favourable soil structure can be maintained.

Comparison of spatial pattern of the predicted ESP and ASWAT scores by indicator-kriging (not shown here) illustrates the notion of the complexity of ESP/soil dispersion interrelationship. The zones with the least probability of having structurally stable soils only partially coincide with zones of high sodicity (i.e. GIS query map: $ESP > 6$). Almost all the zones with low probability of structurally stable soils only partially exhibit high values of ESP. There is thus only a slight spatial correlation between predicted sodic soil (defined by GIS query: $ESP > 6$) and zones of high risk of at least moderate dispersion.

ESI, which is a combined index of EC and ESP (Equation 2), could be considered as a more objective measure of the soil structural stability. Figure 2 displays the high areas with ESI less than the threshold value. A tentative critical ESI value for the Australian cotton soils below which clay dispersion is probable is < 0.05 (McKenzie, 1998). ESI values of less than 0.05 are predominant in the study area, with only isolated zones with ESI greater than 0.05 found in the central and eastern parts of the study area.

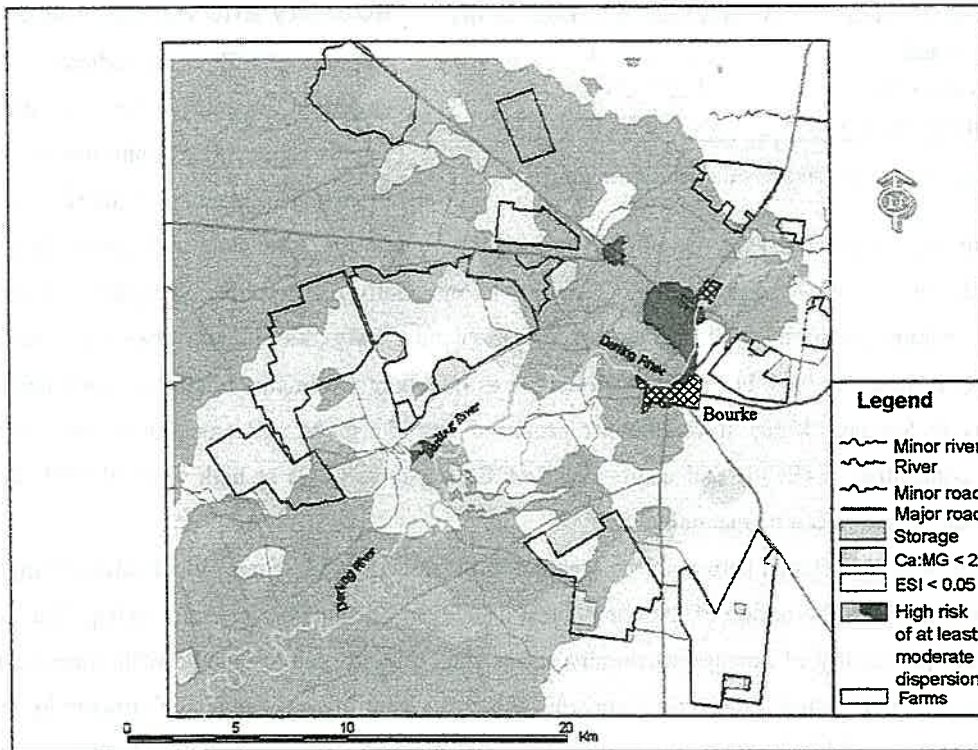
We compared the relationship of ESI, Ca:Mg with the actual likelihood of at least moderate soil dispersion (ASWAT scores > 2). Significant spatial correlation is evident between zones of high risk of at least moderate dispersion (defined by GIS query: likelihood of moderate dispersion > 0.6 probability) and low ESI (GIS query $ESI < 0.05$) as shown in Figure 2. Zones of high risk of at least moderate soil dispersion in the north and the south of the study are also evident in Figure 2. Even though the spatial prediction of sodic soil (GIS query: $ESP > 5$) appears to underestimate dispersion risk zones in the northwest section of the study area, whilst risk zones are overestimated in the southwest, the divergence is captured to some extent by ESI, highlighting the importance of the interaction of EC and ESP in controlling soil dispersion.

In terms of Ca:Mg, the spatial coincidence of zones characterised potentially of at least moderate dispersion and zones of high risk of Ca:Mg ratio below the threshold values is more restricted (Figure 2). However, only a few patched zones, characterised by high risk of Ca:Mg below the threshold, are outside the zones of high risk of moderate dispersion. Caq:Mg is not necessarily a good predictor of soil dispersion at least for the study area.

Spatial analysis of soil sodicity and ASWAT scores

The use of ESP as an indicator of soil structural stability can be directly related to the physical-chemical processes influencing dispersion in soil.

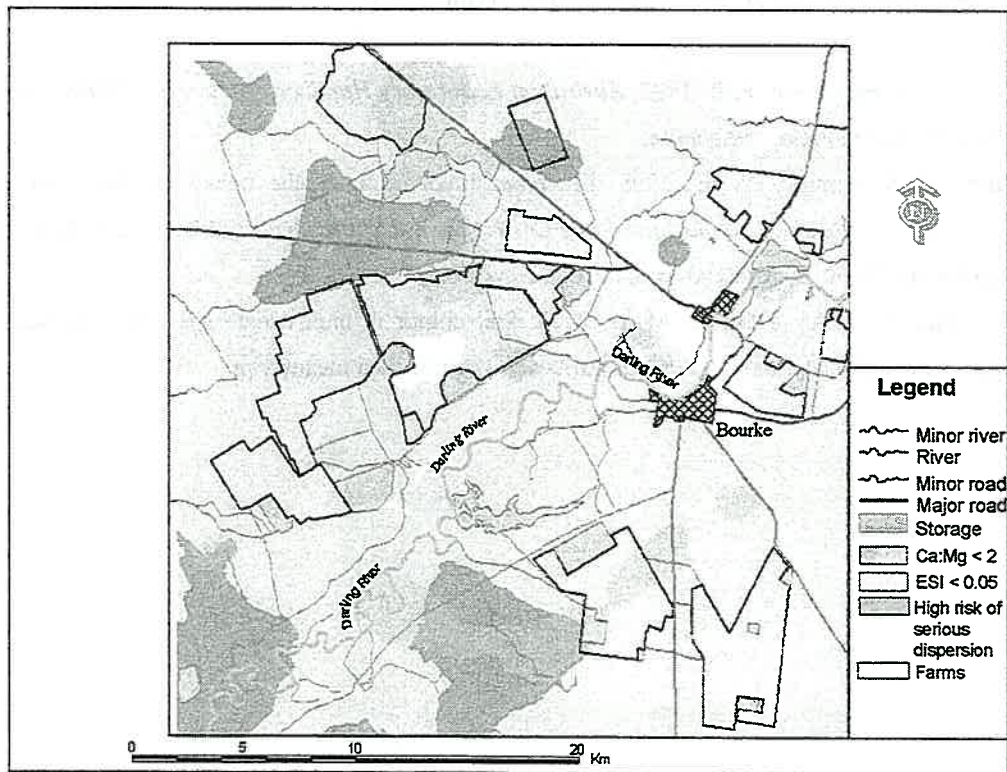
Figure 2. GIS analysis of spatial interaction of ESI, Ca:Mg and high risk of at least moderate soil dispersion



Comparison of probable spontaneous dispersion and predicted ESI is illustrated in Figure 3. It reveals a narrower spatial correlation between these soil quality indicators. Spatial correlations are especially evident between areas with greater than 0.60 probability of moderate dispersion and areas of less than 0.025 ESI. The southwest corner of the study area is predicted to be sodic, with ESP values greater than 5. However, soil with potential moderate dispersion is not highly probable. It is likely that the relatively high EC values as exhibited in this zone impeded the negative impact of high ESP on soil dispersion. These interactions are captured by the ESI, which shows a close spatial pattern with probable moderate dispersion in this zone. Additionally, in the north west of the study area there is a considerably greater area of highly probable moderate dispersion compared to sodic soil ($ESP > 5$). The predicted ESI takes into account the extremely low EC values in this area to identify the zones of potentially dispersive soils. Again ESI and probable moderate dispersion spatially correlate strongly in this area (Figure 2). This confirms the notion adduced by Rengasamy & Sumner (1998) that very low EC values mean that a soil may become dispersive even when the ESP of the soil is as low as 2.

Like the case of moderate dispersion spatial coincidence of zones exhibiting Ca:Mg below the threshold (i.e., < 2) with those of high risk of potential spontaneous dispersion is minimal confirming the notion that Ca:Mg is not all that influential on soil structural degradation.

Figure 3. GIS analysis of spatial interaction of ESI, Ca:Mg ratio and high risk of spontaneous soil dispersion



ESI as a more objective measure of soil dispersion is further supported by the superior correlation between ASWAT and ESI ($r=0.65$) compared to ASWAT and ESP ($r=0.44$). It is implicit that Na^+ and EC are the main driving force behind soil dispersion, and of course the incorporation of EC in deriving ESI improves the prediction of structural stability. The slight variations in spatial pattern between ESI and ASWAT and the less than perfect r values of ASWAT versus ESP and ESI, indicate that other factors, including clay mineralogy and organic content (Field *et al.*, 1997), beside the main driving forces of Na^+ and EC, are influencing aggregate stability as measured by ASWAT. The interaction of these other factors presents some challenges for further studies.

References

- CSIRO. 2001. Commonwealth Scientific & Industrial Research Organisation. www.csiro.au
- Dougherty, W. & Anderson, A. 2001. Sodic soils: their properties and management. In: *Describing, Analysing and Managing Our Soil . First Edition: Proceedings of the DAMOS '99 workshop held at The University of Sydney, November 22nd-26th, 1999.* (eds S. R. Cattle & B. H. George), pp.105-121. Published jointly by The University of Sydney and the Australian Soil Science Society Inc. (NSW Branch).
- Field, D. J., McKenzie, D. C. & Koppi, A. J. 1997. Development of an improved Vertosol stability test for SOILpak. *Australian Journal of Soil Research*, **35**, 843-852.
- Isbell, R. F. 1996. *The Australian Soil Classification*. Australian Soil and Land Survey Handbook. CSIRO Publishing, Melbourne.

- McKenzie D.C. 1998. *SOILpak for cotton growers*, 3rd Edition, NSW Agriculture, Orange.
- Odeh, I. O. A., McBratney, A. B. & Chittleborough, D. J. 1995. Further results on prediction of soil properties from terrain attributes: heterotropic kriging and regression-kriging. *Geoderma*, **67**, 215-226.
- Rayment, G. E. & Higginson, F. R. 1992. *Australian Laboratory Handbook of Soil and Water Chemical Methods*. Inkata Press, Melbourne.
- Rengasamy, P. & Sumner, M. E. 1998. Processes involved in Sodic behaviour. In *Sodic Soils: Distribution, Properties, management and Environmental Consequences* (eds M. E. Sumner and R. Naidu), pp. 35-50. Oxford University Press, New York.
- Warr, B., Odeh, I. O. A., & Oliver, M. A. 2001. Soil colour in multivariate space II: Application to (geo)statistical analysis of soil colour attributes. Unpublished manuscript.