CONFIRMATION OF NITRATE LEACHING POTENTIAL OF SELECTED SOILS IN THE BURDEKIN DELTA REGION

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Abstract

ELECTROMAGNETIC induction instruments (EMI) were used to identify major variation in apparent electrical conductivity of earth (ECa) to depths of 1.5 and 6 m, along five transects in areas of the Burdekin delta that were known to have moderate to high levels of nitrate nitrogen (NO3-N) in irrigation waters drawn from the aquifer. The variation in ECa in the low electrolyte environment was clearly related to clay content of the 0–1.5 and 0–6 m profiles at 11 sites where soil samples were obtained by drilling. Properties of the surface 1.5 m of soil provided a reasonable reflection of deeper soil properties, justifying the use of the former for previous modelling of soil leaching fraction with the SALF model. There was generally good agreement between categories of ECa values and the leaching hazard zones derived from SALF and shown on the 1:50 000 soil map. Several apparent anomalies were identified between boundaries for leaching hazard on the soil map and those inferred from more detailed ECa data. These differences were attributed to the relatively large scale of the soil map, compared to close range ECa data and possible generalisation of soil properties across the various manifestations of comparable soil associations for the modelling. Eight of the 11 drill sites supported NO3-N loadings between 20 and 60 kg/ha in a 6 m profile, but two sites contained 198 and 320 kg/ha each. The 0–3 m zone of the latter two sites contained 89 and 131 kg N/ha and this is potentially accessible to roots of sugarcane. The high NO3-N profiles supported ‘bulges’ in nitrate between 2 and 3 m that were related to changes in soil properties. EMI instruments have a clear role in detailed identification of leaky soils so that more site specific nutrient and water management strategies can be implemented to reduce leaching of nitrate into the aquifer.

Introduction

Canelands of the Lower Burdekin District are located on alluvial soils in the delta of the Burdekin River. Soil associations reflect position of the soil unit with respect to levees and back plain alluvium of former major distributary channels,
minor stream channels or relict alluvium on low lying flats of prior streams (NRM, 2005). Soil mapping was supported by estimates of a leaching fraction (ratio of drainage water to input water) using the SALF model (Shaw and Thorburn, 1984) for each soil association to identify well-drained soils.

This work was undertaken because of concerns with elevated levels of nitrate nitrogen (NO$_3$-N) in the aquifers that underlie soils of the delta (Weier et al., 1999; Biggs et al., 2001) and are used for irrigation and domestic water supply. Bore samples collected by Biggs et al. (2001) on the left bank of the Burdekin River were mainly located on either side of the Old Clare Rd between Clare and Giddy Road while those on the right bank were in a triangle south of the Bruce Hwy and the Burdekin River.

Between October 1998, and June 2000, 21–38% of these bores returned samples with more than 50 mg/L NO$_3$–N, the upper limit for nitrate in drinking water (NHMRC, 1996). The aquifer discharges into the Burdekin and Haughton Rivers, major drainage lines within the delta and directly to the ocean in Bowling Green Bay (Cook et al., 2004). Hence nitrate levels are also relevant to potential environmental impacts discussed by Arthington et al. (1997) and Crossland et al. (1997).

Weier et al. (1999) found an isotopic signature that suggested nitrate in 45% of bore water samples originated from fertiliser nitrogen (N). Thus the levels of N in ground waters and the evidence of anthropogenic origins have implications for nutrient and water management in the Burdekin delta.

This issue has been addressed by recent research and development activity, where nutrient value of N in irrigation water is recognised within the SIX EASY STEPS nutrient management guidelines for the Burdekin region (Schroeder et al., 2009) and is linked to reduced inputs of fertiliser N on farms (S Attard, personal comm.).

However, the question arises as to the co-location of bores with elevated nitrate levels and the soils with high leaching potential. The 2005 soil mapping and leaching fraction exercises were based on soil properties to 1.5 m depth, but there is no information provided about the continuity of leaching potential to greater depths, the nitrate profile above the water table and within the crop root zone.

Thus a field sampling exercise was undertaken in October 2007 to compare soil profile characteristics to 6 m depth with the 2005 mapping of leaching fractions and to determine the nitrate profile in relation to soil properties, prior to accession of nitrate to the aquifer.

**Methodology**

Five transect lines (Figure 1) were chosen on the left and right banks within areas that contained zones of elevated nitrate in ground water. Transects ranged in length from 3.55 to 8.62 km for lines 5 and 3, respectively. Eleven sites were chosen for collection of soil samples to a depth of 6 m based on readings of apparent electrical conductivity (ECa) of earth obtained from electromagnetic induction (EMI) conductivity meters. Profile sites were located on the edge of cane fields or headlands.
ECa is a function of electrolyte concentration, clay content, clay type and moisture content (McNeill, 1980a). In low electrolyte environments the ECa signature is primarily a function of soil texture, with minor influence from soil moisture. Thus EMI instruments can be utilised in such situations to map soil texture groupings. Day and McShane (1986) utilised this technique to show good agreement between soil associations and ECa in toposequence studies on the Burdekin right bank in areas of high and low electrolyte storage. We also have used the technique to delineate soil texture associations in the alluvia of the Indus River in Pakistan (unpublished data). Depth of exploration by EMI instruments is a function of the operating frequency of the instrument, the spacing of transmitter and receiver coils and the dipole orientation (McNeill, 1980b). In particular, the EM31 instrument can provide information for nominal 3 and 6 m soundings (EM31h and EM31v, respectively), while the EM38 instrument provides data to nominal depths of 0.5 and 1.5 m when using the horizontal and vertical modes respectively (EM38h and EM38v).

EMI readings were made at approximately 100 m intervals along each transect and positions were logged by a GPS unit. On completion of the EMI readings, the 11 drill sites were chosen to cover the range in ECa values and hopefully a range of soil textures. Drill sites were completed only on the left bank transects due to time limitations placed on the field study. Samples were taken from a 100 mm open flight
auger drill stem every 0.25 m to 1.0 m, then every 0.5 m to 2.0 m depth and generally at 1.0 m intervals thereafter to 6.0 m depth. Samples were described for colour and texture in the field with two samples being reserved from each interval. Approximately 1 kg of soil was bagged for later analysis of particle size, electrical conductivity (1:5) and pH in all samples and of nutrients in 0–0.25 m zone samples. A second 0.5 kg sample was placed in a field refrigerator and maintained in a cool field moist condition for determination of NO3-N by 0.01 M CaCl2 extraction.

Water soluble NO3-N was extracted 0.01 M CaCl2 in the BSES laboratory in Bundaberg. The CaCl2 technique was employed to aid clarification of the sample. Nitrate values were measured using a Palintest® spectrophotometer after reduction of nitrate to nitrite using a Nitracol® tablet for the diazonium reaction and development of colour. A study was undertaken to compare results from the Palintest® method with those obtained from the BSES Laboratory at Indooroopilly, where CaCl2 extracted nitrate was quantified by flow injection analysis after cadmium reduction of nitrate to nitrite and colour development after the diazonium reaction. A coefficient of determination of 0.87 and a regression coefficient of 0.85 for the comparison allowed the Palintest® instrument to be used with confidence in this exploratory study. A bulk density of 1.3 t/m³ was applied for calculation of NO3-N in soil textures finer than sandy loam and a value of 1.55 t/m³ was applied to coarse sand zones in the profile.

Coordinates for boundaries of soil associations along transect lines were calculated from the 2005 soil map for comparison with ECa values. Soil types relevant to the five transects and leaching fractions calculated by SALF are shown Table 1.

Table 1—Soil types, SALF leaching fraction and leaching hazard class for soils in EMI transects in 2007.

<table>
<thead>
<tr>
<th>Leaching fraction</th>
<th>Hazard class</th>
<th>Soil associations¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.1</td>
<td>Negligible</td>
<td>RUgb, RUgd</td>
</tr>
<tr>
<td>0.1–0.3</td>
<td>Slight</td>
<td>BUfb, BUfc, CUfc, RUgc</td>
</tr>
<tr>
<td>0.3–0.5</td>
<td>Moderate</td>
<td>BUfd,</td>
</tr>
<tr>
<td>&gt;0.5</td>
<td>Marginal</td>
<td>BDba, BUca, BUna, BUm, CUMB</td>
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¹NRM (2005)

Results and discussion

EMI transects

Examination of EC1:5 data for the 11 drill profiles showed that while the survey was conducted in a low electrolyte environment, with EC values ranging between 0.02 and 0.15 (the latter occurred in a few clay zones), there were strong and highly significant linear correlations between ECa values from the EMI instruments and profile weighted average EC1:5 values (Table 2). EC1:5 was influenced by clay content of the profile (Table 2) and there were highly significant linear correlations between ECa and clay% that allowed use of the EMI instruments to survey soil texture in this environment.
Table 2—Statistics for relationships between EMI readings, EC1:5 and clay% at drill sites, where R² = coefficient of determination, p = probability value and N = number of samples.

<table>
<thead>
<tr>
<th>Variables</th>
<th>R²</th>
<th>p</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM31v and EC1:5_6 m</td>
<td>0.87</td>
<td>0.0000</td>
<td>11</td>
</tr>
<tr>
<td>EM38v and EC1:5_1.5 m</td>
<td>0.78</td>
<td>0.0003</td>
<td>11</td>
</tr>
<tr>
<td>EC1:5_6m and clay%_6 m</td>
<td>0.71</td>
<td>0.001</td>
<td>11</td>
</tr>
<tr>
<td>EC1:5_1.5m and clay%_1.5 m</td>
<td>0.54</td>
<td>0.01</td>
<td>11</td>
</tr>
<tr>
<td>EM31v and clay%_6 m</td>
<td>0.65</td>
<td>0.002</td>
<td>11</td>
</tr>
<tr>
<td>EM38v and clay%_1.5 m</td>
<td>0.70</td>
<td>0.0014</td>
<td>11</td>
</tr>
</tbody>
</table>

There is a strong similarity in the pattern and values for ECa to nominal depths of 1.5 m (EM38v) and 6 m (EM31v) over the five survey lines (Figures 2–6). This suggests that near surface properties are reasonable representations of deeper profile textures and that it was appropriate to use properties of the shallow zone to model profile drainage for the 2005 soils map. EM31v readings are lower than those for EM38v at some locations on the transects. Drill site logs show that this difference in ECa values is associated with lower clay content below approximately 4 m where we encountered coarse sands and gravels of upper beds of the aquifer (drop in clay%, Figure 7). The very low clay content at site 8 was due to a continuous profile of coarse sand below 1 m (Figure 7). Horizontal dipole data for either electromagnetic instrument did not add value to interpretations and are not discussed in this paper.

EMI values and leaching characteristics of soil
Of the 11 drill sites, 8 were located in the ‘marginal’ to ‘moderate’ categories with leaching fractions greater than 0.3 and had ECa values <30 mS/m for EM31v;
two sites were located in the ‘slight’ hazard zone with a leaching fraction 0.1–0.3 and EM31v values of 50–60 mS/m; one site was classified in the ‘negligible’ category with leaching fraction <0.1 and EM31v values >60 mS/m (Figures 2–6).

ECa data for the transects generally support the conclusion that higher values of ECa are associated with less leaky profiles and that sites with leaching fractions greater than 0.5 tend to have lowest ECa values. However the extra detail provided by the ECa data does raise several questions in relation to appropriateness of the mapped leaching classifications. Profile log data show that site 3 had a clay-loam to clay profile and ECa values to the east of the site exceeded 40 mS/m (Figure 2), suggesting potential for a larger zone of the RUgc (‘slight’ hazard) soil association than was mapped.

Conversely, ECa data for the western end of Line 1 suggest that much of the ‘slight’ hazard BUfb zone is more likely to be in the ‘moderate’ leaching fraction category.

The profile log for site 7 (data not provided) showed a generally clayey profile with only two 1 m zones of sandy loam starting at 2.2 and 4 m. The soil map information on Line 3 (Figure 4) shows a zone of approximately 870 m of the ‘slight’ hazard RUgc at site 7 adjoined to the east and west by similarly sized zones of ‘moderate’ hazard BUfc association.

ECa data suggest potential for reduction in the area classified as ‘moderate’ hazard. ECa data for Line 4 (Figure 5) suggests an unmapped area of ‘slight’ leaching hazard near the 2750 m mark on the transect and that the ‘slight’ hazard Bufd zone between 3600 and 4700 m is likely to have a ‘moderate to marginal’ leaching hazard. Similarly ECa data for Line 5 (Figure 6) suggest that the mapped BUfc ‘slight’ hazard and RUgd ‘negligible’ zones are more leaky than indicated by model data.
Several sources of variation may contribute to differences between leaching hazard classifications from ECa and soil map data. The soil map is published at 1:50 000 scale and it is generally recognised that position of soil association boundaries may not be accurate at farm block level, or for GPS locations obtained generally with ±5 m accuracy.

Fig. 4—Values of ECa in relation to mapped soil association boundaries and SALF estimates of leaching fraction for the Line 3 transect.

Fig. 5—Values of ECa in relation to mapped soil association boundaries and SALF estimates of leaching fraction for the Line 4 transect.
Soil association boundaries are often inferred from aerial photography in relation to location of key profile descriptions and soil surveyors and agronomists recognise that some variation in soil properties can occur within soil associations. Thus relevance of the SALF predictions depends very much on the data used in the simulation.

Fig. 6—Values of ECa in relation to mapped soil association boundaries and SALF estimates of leaching fraction for the Line 5 transect.

Fig. 7—Depth profile of clay % for five drilling sites on transect lines 1–3.
Soil nitrate profiles

NO$_3$-N loading in the profile was calculated to display the agronomic and environmental significance of nitrate retention. Most of 6 m soil profiles that were sampled showed loadings between 20 and 60 kg/ha (Table 3). However, notable exceptions were the 12 kg/ha present at site 9 and 198 and 320 kg/ha present at sites 8 and 5, respectively. Site 5 is on Leibrecht Rd and is mapped with ‘marginal’ leaching hazard soils to the west and east (Figure 2).

Site 8 (Figure 4) is to the east of the Bruce Hwy on Line 3 and is an extremely sandy profile (Figure 7). The two profiles with highest NO$_3$-N loadings showed distinct ‘bulges’ in NO$_3$-N concentrations in the 2–3m depth interval (Figure 8), whereas profiles with lower loadings showed low and generally flat concentration profiles below about 0.5 m.

The NO$_3$-N ‘bulge’ at site 5 may be associated with the change in texture from sandy-loam / sandy clay loam above 1.5 m to lower hydraulic conductivity clay loam between 2 and 4 m. This change in texture is reflected in the clay profile (Figure 7). As mentioned above, site 8 was extremely sandy below 1m, but the NO$_3$-N ‘bulge’ at 3 m may be associated with the major increase in the fine sand fraction between 2 and 3 m. The fine sand fraction rose from 15% in the 1.5–2 m zone to 31% in the 2–3 m zone. It is hypothesised that fine sand may have reduced porosity of the coarse sand and thus the rate of leaching of NO$_3$-N.

The low NO$_3$-N levels for site 2 below 0.75 m (Figure 8) and the soil’s low NO$_3$-N retention (Table 3) are a reflection of low leaching potential due to the high clay content of this profile (Figure 7).

Conversely, the low NO$_3$-N profile for site 1 (Figure 7) and its low retention of NO$_3$-N is most likely a function of continually coarsening of texture with depth so that NO$_3$-N is not retained by the lower hydraulic conductivity materials identified at sites 5 and 8.

| Table 3—NO$_3$-N loading (kg/ha) at different depth intervals in 11 deep profiles in the Burdekin delta in October 2007. |
|---|---|---|---|
| Line # | Site # | kg NO$_3$-N/ha |
|       |       | 0–3 m | 3–6 m | 0–6 m |
| 1     | 3     | 18    | 42    | 60    |
| 1     | 4     | 16    | 18    | 34    |
| 1     | 5     | 189   | 131   | 320   |
| 2     | 1     | 13    | 13    | 26    |
| 2     | 2     | 23    | 12    | 25    |
| 2     | 6     | 15    | 32    | 47    |
| 3     | 7     | 25    | 31    | 49    |
| 3     | 8     | 109   | 89    | 198   |
| 3     | 9     | 6     | 6     | 12    |
| 3     | 10    | 16    | 16    | 32    |
| 3     | 11    | 10    | 11    | 21    |
Summary and conclusions

Major variation in ECa within the low electrolyte environment of the study area was related to variation in soil texture of 1.5 and 6 m deep profiles. Thus ECa from EM31 and EM38 instruments could be used to identify zones of different texture and potential for leaching nutrients.

The general similarity of patterns and levels of ECa for 1.5 and 6 m profiles confirmed that near surface soil properties could provide a reasonable reflection of leaching potential for deeper profiles in this environment.

Several apparent anomalies were identified between boundaries for leaching hazard based on SALF model data and those inferred from ECa data.

These differences were attributed to the relatively large scale of the soil map, compared to close range ECa data and possible generalisation of soil properties across the various manifestations of comparable soil associations.

Eight of the 11 drill sites supported NO₃-N loadings between 20 and 60 kg/ha in a 6m profile, but two sites contained 198 and 320 kg/ha each. The 0–3 m zone of the latter two sites contained 89 and 131 kg N/ha and this is potentially accessible to roots of sugarcane if there is sufficient residence time in the profile.

The high NO₃-N profiles supported bulges in nitrate concentration between 2 and 3 m that were related to changes in soil properties.
The challenge to reducing the leaching of NO$_3$-N into the Burdekin aquifer is to apply more site specific nitrogen and water management to the leaky soils. Fertilisation strategies include the already identified reduction in, or elimination of, N fertiliser input based on the N in irrigation water.

Split application of N fertiliser is another strategy to reduce losses and recognition of the organic matter levels in surface soils will also result in small adjustments to N fertiliser inputs (Wood et al., 2003).

Site specific irrigation management in this environment is more difficult to achieve, but some gains could be achieved by optimising furrow length, furrow shape and in-flow volume for leaky soils. A longer-term move to overhead irrigation would allow more control over the quantum of applied irrigation water.

This study has confirmed the presence of moderate to high levels of NO$_3$-N within the soil profile before its accession to the aquifer.

We have also shown that EMI surveys have the potential to identify the leaky zones in more detail than is available from large scale soil maps.

**Acknowledgements**

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**REFERENCES**


