Queensland Journal of Agricultural and Animal Sciences Vol. 45 (2), 89-96 (1988)
Published by the Queensland Department of Primary Industries

Chloride leaching in a newly irrigated sodic duplex soil from the Burdekin River Irrigation Area

A. J. Dowling and P. J. Elliot

Department of Primary Industries, PO Box 591, Ayr, Q. 4807, Australia.

Abstract

An investigation was undertaken to describe chloride and water movement in a newly irrigated sodic duplex Gaynor soil from the Burdekin River Irrigation Area, north Queensland. After landforming, this sodic duplex soil is considered suitable for irrigation of rice but marginal for irrigation of row crops due to the need for further amelioration.

In this unreplicated study, chloride leaching was observed under both furrow and ponded irrigation. In furrow irrigated plots, gypsum influenced root zone hydrology such that greater chloride leaching and, hence, infiltration occurred. Chloride leaching, however, decreased with distance along the furrow suggesting 'intake opportunity time' decreased down the furrow. This has management implications in terms of obtaining uniform water application with minimal runoff and deep drainage losses. Under ponding, chloride leaching was not clearly related to landforming or use of gypsum but did appear consistent with ponding plus some form of subsurface drainage, in this case via gravel layers. Use of gypsum increased water use raising the question of increased deep drainage and accessions to local and regional groundwater systems.

INTRODUCTION

Sodic duplex soils occupy some 32 550 ha or 22% of the new Burdekin River Irrigation Area (BRIA) (Thompson 1977; Reid and Baker 1984). In these soils, high levels of subsoil salinity and sodicity are likely to create problems under irrigation (Smith and McShane 1981; Gardner and Coughlan 1982). Land use assessments indicate these soils are suitable for rice, depending on slope, and marginal for row crops using existing irrigation and crop production techniques (Donnollan *et al.* 1986). Agronomic trials have identified poor crop establishment and water stress as factors limiting yield. Poor crop establishment was associated with exposure of sodic subsoils during landforming and water stress due to limited infiltration and low plant available water capacity (Elliot and McDonald 1987).

Previous work indicates that gypsum will influence chloride leaching in sodic soils (see for example, Loveday 1976; McIntyre *et al.* 1982). Gypsum dissolution, through cation exchange effects or by increasing the electrolyte concentration in the percolating solution, will maintain soil macroporosity (McIntyre *et al.* 1982) by suppressing slumping and dispersion in both surface and subsoil (Loveday 1976). Surface soil structure will improve (Smith and McShane 1981) while root zone salinity and soil strength decrease (Gardner and Coughlan 1982).

Sodic duplex soils occur within areas potentially commanded by water from the Elliot Main Channel when irrigation farms on the Right Bank of the BRIA are released. In this preliminary and unreplicated study, the initial effect of furrow irrigating and ponding a sodic duplex soil after incorporation of gypsum is described. Variations in chloride leaching are assessed in terms of particular site management parameters and related to water entry and redistribution within the profile. The parameters were distance along the furrow in furrow irrigated plots and soil movement during landforming in ponded plots.

MATERIALS AND METHODS

Study site

Data were collected on the Gaynor research site (AMG Ref. Zone 55K, 29280E 780437N, elevation 33 m above sea level), 24 km south-west of Home Hill, Queensland. The site, on gently sloping (0.5 %) pediments below Mt. Louisa, is located on the Right (southern) Bank of the Burdekin River adjacent to the Elliot Main Channel, 4 km from the balancing storage.

Soils of the study site have been mapped as the Gaynor soil type (solodic-solodised solonetz, Dy2.43 (Northcote 1974), 1Dyc (Thompson 1977), Typic Natrustalf). In their undisturbed state, these are duplex soils of colluvial origin with shallow (<0.15 m), hardsetting surface horizons overlying highly sodic and saline subsoils (Donnollan *et al.* 1986). An associated cracking clay soil (Ug3.2, Typic Pellustert) also occurs within the site (<20% of the mapped area). Discontinuous layers of gravel (2-6 mm diam.) occur at depths between 0.8 and 1.5 m. These gravel layers may act as preferential pathways for water movement in these soils. Some properties of this soil are shown in Table 1.

Table 1. Selected properties of this Gaynor soil

Depth m	pH[1]	EC[1]	ESP[2]	CEC[3]	Clay %	<20 µm dispersion ratio	Bicarb extr. P mg/kg	Tot. N %	Repl.[4] K.
0–0.1	6.7	0.02	5	110	25	0.79	2	0.085	3.2
0.1–0.2	8.5	0.19					2	0.055	2.0
0.2–0.3	9.1	0.43	19	270	34	0.89			
0.5–0.6	9.1	1.04	32	290	37	0.98			
0.8–0.9	8.6	0.92	32	280	42	0.98			
1.1–1.2	8.5	0.75	30	260	43	0.99			

1. 1:5 soil:water suspension at 25°C.
2. Exchangeable sodium percentage.
3. Cation exchange capacity (alcoholic 1 M NH_4Cl at pH 8.5), (mmol(+)/kg),
4. Replaceable potassium (mmol(+)/kg).

Plot establishment

Initial site development and agronomic aspects of the first irrigated crops grown (December 1985 to May 1986) are described by Elliot and McDonald (1987). The site (Figure 1) was deep ripped to 0.35–0.4 m (23 July 1985) before planting the first furrow irrigation (F) and ponded (P) crops. The F and P plots were landformed, on the basis of topographic surveys, with soil removed from areas of higher elevation (cut) and relocated to areas of lower elevation (fill). The F plot was landformed (maximum depth of earthworks 60 mm) then laser graded to a downslope gradient of 0.00106 m/m. Plot dimensions were: field length 325 m and width 62.5 m; furrow length 315 m; furrow spacing 0.75 m. For P plots, five 0.45 ha experimental areas (bay size after installation of banks 55 m by 60 m) were developed. The maximum depth of earthworks was 180 mm. This resulted in exposure of sodic subsoils. Bays were laser graded to 0.001 m/m.

Prior to planting the second crop, the F plot was split and two unreplicated 0.9 ha experimental areas, furrow plus gypsum (F+G) and furrow minus gypsum (F−G), were established. Two unreplicated P plots, pond plus gypsum (P+G) and pond minus gypsum (P−G), were also established. Gypsum (20 t/ha) was incorporated (12 June 1986) into the surface 0.1 m of the F+G and P+G plots. F and P plots were sown to maize (*Zea mays* L., 20 June 1986) and rice (*Oryza sativa* L. cv. Lemont, 24 July 1986) respectively.

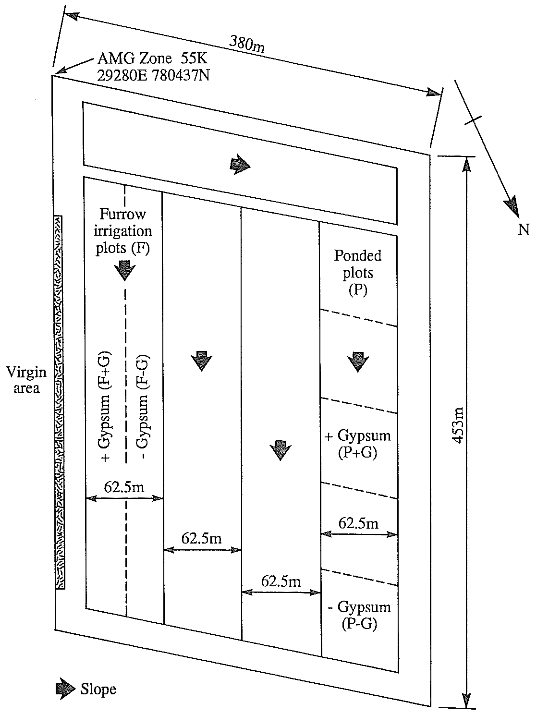

Figure 1. Plan of Gaynor research site illustrating the locations of the virgin reference area and the four experimental plots.

Irrigation management

Plots were irrigated with water from the Elliot Main Channel. Water quality (EC 0.2 dS/m, SAR 1.5 and residual alkali 0.7 mmol/L) was such that yield reductions were unlikely, according to conventional criteria (see for example Shaw *et al.* 1987).

For F plots, irrigations were scheduled according to the water requirements of the F−G plot. Water was metered onto both F+G and F−G plots when cumulative Class A Pan evaporation reached 60 to 65 mm (Table 2). This corresponded to a soil water deficit of 50 to 55 mm in the F−G plot, being approx. 80% of the estimated plant available water capacity of this soil (Gardner and Coughlan 1982). F+G plots were irrigated nine (eight for F−G) times over 110 days (25 June to 13 October 1986). Irrigation intervals were 8 to 10 days. Irrigation frequencies were the same for both F+G and F−G plots.

Irrigations were managed to minimise runoff. This was achieved by stopping inflow (cutoff) when the advancing irrigation front reached the end of the furrow. Furrows were open ended to reduce waterlogging and runoff was measured through a Parshall flume. Irrigation advance relations were developed for both F+G and F−G plots with irrigation start and cutoff times recorded and inflow rates (L/sec) measured (Figure 2).

In the P plots, water was metered onto individual bays (Table 2). Both P+G and P−G plots were managed similarly. Plots were flushed twice (25-27 July and 6 August 1986) by ponding to a water depth of approx. 20 mm for <24 hr. Permanent flood was maintained for 76 days (4 September to 19 November 1986) at about 100 mm depth by metered water additions (toppings) every two to three days. Toppings did not cause runoff. Runoff occurred only after rain and was measured through a 'V' notch weir.

Table 2. Total water use under furrow (maize) and ponded (rice) irrigation for crops grown June to November 1986

Irrigation method	Water applied less runoff (mm)[1]	
	no gypsum	plus gypsum[2]
Furrow		
1st irrigation	92	130
subsequent irrigations	327	430
total[3]	419	560
Pond		
flushing	260	313
permanent flood	149	128
toppings	490	680
total	899	1121

1. This data does not include rainfall of 96 mm over this period.

2. Gypsum applied at 20 t/ha.

3. In total, eight irrigations for minus gypsum and nine irrigations for plus gypsum plots.

Soil sampling and analysis

Soil profiles to 1.6 m were collected for analysis after harvest (November–December 1986). Each profile was a composite of three cores, taken 1 m apart and 5 m apart for F and P plots respectively. The cores were visually assessed as morphologically similar before bulking. The presence and depth of gravel was also noted.

Within F plots, four composite profiles were collected at distances of 50, 125, 200 and 260 m from the head ditch. Zero depth was taken as the levelled landsurface before hills and furrows were formed.

Within P plots, three composite soil profiles were collected. Profiles were sampled from areas reflecting up to 0.18 m of soil removal (cut), no soil movement (nil) and up to 0.18 m of soil addition (fill). Zero depth was taken as the soil surface after landforming.

Samples were also taken from an undisturbed (virgin) area to provide baseline data (Figure 1). Four composite profiles were collected similarly to the F plots. This area was cleared and deep ripped during site development but not irrigated or treated with gypsum. Also, field saturated hydraulic conductivity (Ks, m/day) was measured at 5 sites (0.1–0.4, 0.4–0.7, 0.7–1.0 m depths) using tube well infiltrometers after Talsma and Hallam (1980).

Soil profiles were partitioned into 0.1 m increments, dried (40°C) and ground (<2 mm) before analysis for chloride (mg/kg) on a 1:5 soil water suspension (after Bruce and Rayment 1982). Further, a single bulk profile (0–0.1, 0.2–0.3, 0.5–0.6, 0.8–0.9, 1.1–1.2, 1.4–1.5 m depths) from each plot was prepared for saturation extract analysis using a mechanical vacuum extractor (16 h extraction) after Dowling and Howitt (1987). Extracts were analysed manually for sulphate (mmol/L) using barium chloride with a turbidimetric finish (Garrido 1964).

RESULTS

Chloride profiles from the virgin area were similar to those from other undisturbed Gaynor soils in the BRIA (Ahern *et al.* 1986). Since virgin chloride profiles did not appear to vary systematically, a mean virgin chloride profile was determined (Figure 3).

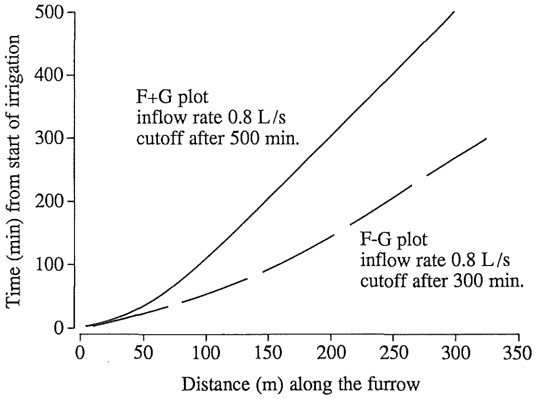

Figure 2. Irrigation advance relations for plus gypsum (F+G) and minus gypsum (F–G) furrow irrigated plots. Inflow rates and cutoff times are shown.

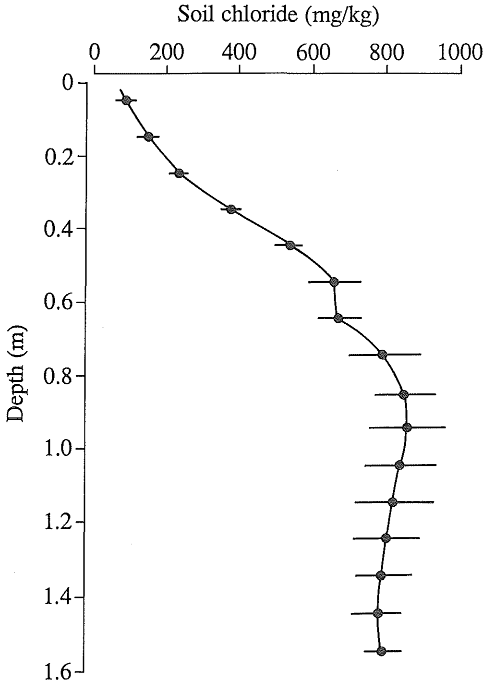

Figure 3. Mean virgin chloride profile. Horizontal lines show the standard error for each 0.1 m depth increment.

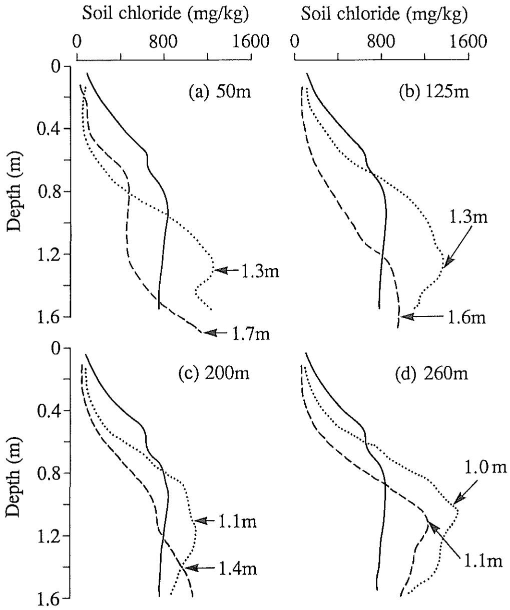

Figure 4. Chloride profiles for furrow irrigated plots minus gypsum and plus gypsum at distances of (a) 50 m; (b) 125 m; (c) 200 m; and (d) 260 m along the furrow. Arrows show depth of maximum chloride in irrigated profiles.

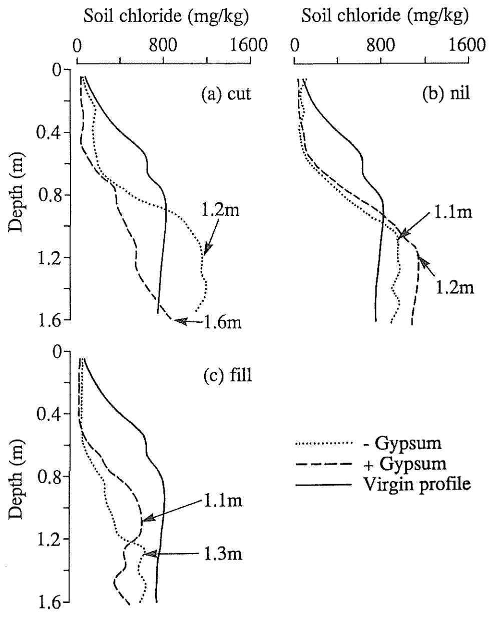

Figure 5. Chloride profiles for ponded plots minus gypsum and plus gypsum after landforming; (a) cut; (b) nil; and (c) fill. Arrows show depth of maximum chloride in irrigated profiles.

Chloride profiles for F−G and F+G plots were compared to the mean virgin profile (Figure 4). For each irrigated profile, depth of maximum chloride was determined (arrows in Figure 4.) as this describes the potential limit to the root zone (Gardner and Coughlan 1982). Changes in this depth, relative to the virgin profile, reflect the extent of chloride leaching in the profile. Figure 4 shows greater chloride leaching in F+G relative to F−G plots at equivalent distances along the furrow. Figure 4 also indicates chloride leaching tends to decrease with distance along the furrow. These observations suggest an inverse relation between chloride leaching and distance in F plots.

Chloride profiles for P−G and P+G plots were similarly related to the mean virgin profile and depth to maximum chloride determined (Figure 5). For both plots, chloride was almost completely removed from the upper 0.6 m. Below this depth, chloride profiles were variable. Chloride leaching appeared unrelated to either soil movement during landforming or use of gypsum. In P plots, gravel was observed during sampling P−G nil and P−G fill areas at 0.9–1.2 m depth.

Saturated hydraulic conductivity (Ks) data for virgin soils are summarised in Table 3. Ks data were high and variable in the 0.1–0.4 m zone. Below this depth, Ks decreased and became less variable. Sulphate concentrations in soil saturation extracts are shown in Table 4. Table 4 shows that redistribution of applied gypsum relative to native gypsum occurred to 0.6 m in F plots and to below 1.5 m in P plots.

Table 3. Saturated hydraulic conductivity for virgin Gaynor soils

Depth interval m	n	Saturated hydraulic conductivity[1] mean (SE.) m/day	Saturated hydraulic conductivity[1] range m/day
0.1 - 0.4	5	1.2 (0.7)	0.006 - 3.6
0.4 - 0.7	5	0.005 (0.001)	0.004 - 0.008
0.7 - 1.0	5	0.02 (0.01)	0.003 - 0.03

1. using tube well infiltrometers (after Talsma and Hallam 1980).

Table 4. Concentrations of sulphate in saturation extracts of Gaynor soils from virgin, furrow irrigated (plus and minus gypsum) and ponded irrigation (plus and minus gypsum) treatments

Depth interval m	Virgin mmol/L	Furrow no gymsum mmol/L	Furrow plus gypsum[1] mmol/L	Ponded no gymsum mmol/L	Ponded plus gypsum[1] mmol/L
0.1	0.4	0.4	20	0.6	25
0.2–0.3	0.7	0.8	2.5	0.6	7.0
0.5–0.6	2.3	3.9	4.4	1.3	3.8
0.8–0.9	3.3	4.1	2.9	3.0	6.5
1.1–1.2	3.4	3.6	3.9	3.8	7.5
1.4–1.5	3.4	2.9	3.8	3.6	6.0

1. Gypsum applied at 20 t/ha.

DISCUSSION

Virgin soil

From the virgin chloride profile, which reflects the equilibrium between water infiltration, water extraction by plants and deep drainage (Shaw *et al.* 1987), aspects of soil hydrology can be inferred. In this virgin soil (Figure 3), water entry into the profile and water extraction by plants occurs in the upper 0.6 m, with water moving freely through cracks to 0.4 m (Table 3). Little water movement occurs below 0.6 m. High sodicity (ESP >25) and dispersion (<20 µm dispersion ratio >0.95) below 0.3 m (Table 1) suggest very low hydraulic conductivity in the subsoil. This was supported by Ks data which show a throttle at 0.4–0.7 m (Table 3). Below the throttle, variations in chloride levels suggest some preferential water movement to depth. This may reflect the presence of discontinuous layers of coarse fragments in the subsoil.

Furrow irrigated plots

Since gravel was not observed while sampling F plots, differences in chloride leaching may be ascribed to both the use of gypsum and distance along the furrow.

As water applied during irrigation provides a mechanism for chloride leaching, depth of maximum chloride reflects the volume of water moving into the soil and the hydraulic properties of the soil. From Figure 4, chloride leaching decreases with distance along the furrow. This suggests as distance increases, infiltration decreases and less water moves to depth. In addition, more chloride leaching occurred in F+G relative to F−G plots at equivalent distances along the furrow reflecting greater infiltration after incorporation of gypsum. This, coupled with a slower irrigation advance in F+G relative to F−G plots (Figure 2), indicates the time free water was present on the soil surface or 'intake opportunity time' decreases with distance along the furrow. In the plus gypsum plot, greater chloride leaching was also accompanied by sulphate redistribution to about 0.6 m (Table 4) and an overall 30% increase in water use (Table 2) despite the presence of a throttle at 0.4 to 0.7 m (Table 3).

The results have implications in terms of irrigation management. An efficient irrigation design should aim to optimise 'intake opportunity time' in order to achieve uniform application of water by minimising deep drainage and runoff losses, as well as irrigation frequency for optimal crop growth. Apart from soil factors of infiltration rate and hydraulic conductivity (which should not be assumed uniform along a furrow), the degree of leaching will be a consequence of 'intake opportunity time'. In this case, 'intake opportunity time' decreases along the furrow in response to management factors (such as application rate and duration, furrow gradient, use of gypsum) particular to the site. This suggests current furrow irrigation management practices and, consequently, water use efficiency are less than optimal for this soil. This is further discussed elsewhere (Dowling *et al.* 1988).

Ponded plots

Chloride leaching was not consistently related to either soil movement due to landforming or incorporation of gypsum (Figure 5). This was surprising, since greater chloride leaching has been ascribed to use of gypsum in other ponded soils from the BRIA (Smith and McShane 1981; Gardner and Coughlan 1982) and elsewhere (McIntyre *et al.* 1982). In this study, any increase in chloride leaching due to gypsum appears masked by the presence of gravel layers in the subsoil. These layers may provide preferential pathways for water movement to depth and appear to influence chloride leaching to a greater extent than either landforming or gypsum.

Both P plots had similar water requirements up to permanent flood (Table 2). The P+G plot, however, required 190 mm or about 40% more water than the P−G plot as toppings necessary to maintain permanent flood during crop growth. These observations suggest the throttle (Table 3) functioned similarly in both P plots to initially restrict water movement to depth. After establishment of permanent flood, the significance of the throttle appeared to decrease. In these plots, water applied as toppings should reflect Ks in the subsoil, given similar evapotranspiration demands for both plots. A greater water requirement as toppings in the plus gypsum plot therefore suggests a higher Ks in the subsoil. This may be ascribed to use of gypsum as indicated from the redistribution of sulphate to below 1.5 m in the plus gypsum plot (Table 4) and is consistent with the findings of Loveday (1976) and McIntyre *et al.* (1982).

Increased water use has serious implications, both on a local and a regional scale, in terms of increased deep drainage, increased salt and water accessions to groundwater and, hence, future problems of waterlogging and salinity.

References

Ahern, C. R., Baker, D. E., and Reid, R. E. (1986), *Soil salinity factors for soil groups: Burdekin Irrigation Area,* Queensland Department of Primary Industries Bulletin QB86002.

Bruce, R. C., and Rayment, G. E. (1982), *Analytical methods and interpretations used by the Agricultural Chemistry Branch in soil and land use surveys*, Queensland Department of Primary Industries Bulletin QB 82004.

Donnollan, T. E., McClurg, J. I., and Tucker, R. J. (1986), *Soils and land suitability of Leichhardt Downs Section, Burdekin River Irrigation Area. Part A. Summary of soils and land suitability assessment,* Queensland Department of Primary Industries, Land Resources Bulletin QV 86001.

Dowling, A. J., Elliot, P. J., Thorburn, P. J., Ross, P. J. and Hunt, S. B. (1988), *Chloride and water movement in a furrow irrigated sodic duplex soil from the Burdekin River Irrigation Area,* Soil Management '88 Symposium, Darling Downs Institute of Advanced Education, Toowoomba, Queensland.

Dowling, A. J., and Howitt, C. J. (1987), Effects of extraction technique on concentrations of soluble salts in soil saturation extracts. *Australian Journal of Soil Research* **25**, 137–44.

Elliot, P. J., and McDonald, W. J. (1987), *Gaynor research site. 1. Progress report—Wet season 1985-86.* Queensland Department of Primary Industries Report RQT 87005.

Gardner, E. A., and Coughlan, K. J. (1982), *Physical factors determining soil suitability for irrigated crop production in the Burdekin—Elliot River area.* Queensland Department of Primary Industries, Agricultural Chemistry Branch Technical Report 20.

Garrido, M. L. (1964), Determination of sulphur in plant material, *Analyst.* **89**, 61–66.

Loveday, J. (1976), Relative significance of electrolyte and cation exchange effects when gypsum is applied to a sodic clay soil, *Australian Journal of Soil Research* **14**, 36–71.

McIntyre, D. S., Loveday, J., and Watson, C. L. (1982), Field studies of water and salt movement in an irrigated swelling clay soil. I. Infiltration during ponding. II. Profile hydrology during ponding. III. Salt movement during ponding. *Australian Journal of Soil Research* **20**, 81–105.

Northcote, K. H. (1974), A Factual Key for the Recognition of Australian Soils. *4th Edn., Rellim Technical Publications, Glenside, South Australia.*

Reid, R. E., and Baker, D. E. (1984), *Soils of the lower Burdekin River - Barratta Creek—Haughton River area, north Queensland.* Queensland Department of Primary Industries, Agricultura Chemistry Branch Technical Report 22.

Shaw, R. J., Hughes, K. K., Thorburn, P. J., and Dowling, A. J. (1987), Principles of landscape, soil and water salinity—processes and management options. Part A, in *Landscape, Soil and WaterSalinity,* Proceedings of the Brisbane regional salinity workshop, Brisbane, May 1987. Queensland Department of Primary Industries Conference and Workshop series QC 87003.

Smith, G. D., and McShane T. J. (1981), *Modification and management of irrigated soils in the lower Burdekin Valley, Queensland,* Queensland Department of Primary Industries, Agricultural Chemistry Branch Technical Report 17.

Talsma, T., and Hallam, P. M. (1980). Hydraulic conductivity measurement of forest catchments. *Australian Journal of Soil Research* **30**, 139–48.

Thompson, W. P. (1977) *Soils of the lower Burdekin River—Elliot River area, north Queensland,* Queensland Department of Primary Industries, Agricultural Chemistry Branch Technical Report 10.

(Accepted for publication 5 December 1988)