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AGRICULTURAL CHEMISTRY BRANCH
TECHNICAL REPORT NO. 14

Queensland Department of Primary Industries, 1979

Queensland Government Technical Report

For information about this report contact soils@qld.gov.au

Agricultural Chemistry Branch
Technical Report No. 14

ISSN 0312- 9926

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DEPARTMENT OF PRIMARY INDUSTRIES, QUEENSLAND

1979

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1. INTRODUCTION

1.1 Historical

According to Murphy and Easton (1950), European settlement in the Byee flats area on Barambah Creek commenced in 1844 when Mondure Station was occupied. From the above authors, it appears that the area was sub-divided for grazing farms between 1900 and 1912. Maize production seems to have been the major pursuit on these units until dairying came to prominence between 1911, when a butter factory started production at Murgon, and 1923 when the Murgon to Proston railway was opened. Dairying has declined in importance since the late 1950's and there are now only about seven farms with milking herds in the area. Grain cropping is now the most important farm enterprise with common crops being barley, sorghum, soybeans, wheat and sunflowers. Though there has been some farm amalgamation, there are still some holdings of around 50 ha.

The potential of the area for intensive irrigation development has been recognized for many years. A public meeting was held in 1925 to organize an approach to the State Government requesting the provision of an assured irrigation water supply. More recently, an economic investigation (C.P. Hamilton 1973 unpublished data) was favourable to intensive irrigation development but it included the lot feeding of beef cattle so many of its assumptions and conclusions were rendered invalid when a slump occurred in the beef industry. A reconnaissance land classification of the flats and surrounding areas was made in 1973 (A.K. Wills, unpublished data) but the entire flats area was included in the one mapping unit.

1.2 Purpose and Extent of Soils Studies

1.2.1 General

Following public meetings in Murgon and Nanango the Queensland Water Resources Commission undertook investigations in the Barker and Barambah Creeks area into the feasibility of constructing a major storage and ancillary works to provide additional water supplies for irrigation. The Department of Primary Industries assisted in assessing the agricultural and economic aspects of the proposals.

As the largest area likely to receive additional irrigation water is the Byee flats area on Barambah Creek, it was decided to undertake soil survey and soil physical investigations to provide data on the suitability of this area for irrigation.

1.2.2 Soil Survey

The only descriptions of the soils of the area that were available were those of Isbell *et al.* (1967) and Wills (A.K. 1973 unpublished data). A detailed reconnaissance soil survey at a scale of 1:50 000 was undertaken covering 6140 ha of the alluvial flats in the Byee area. The approximate area surveyed is shown in Figure 1. The objectives of the survey were to describe and map the soils of the area to assess their suitability for irrigation and to serve as a base for soil physical and land use studies.

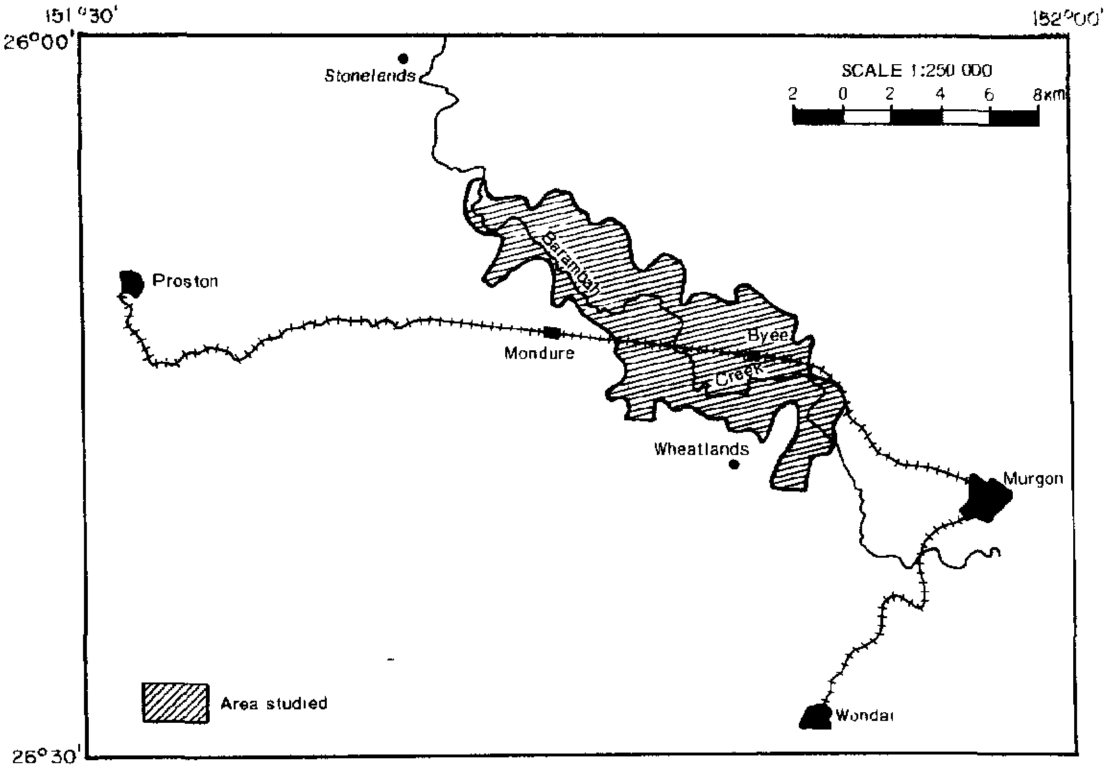


Figure 1 Locality plan

1.2.3 Soil Response to Irrigation

No data was available on the effect of irrigation on the soils of the area so a series of soil investigations were carried out with the following objectives:

(a) To examine the effects of existing irrigation with creek and underground water on soils of the major soil profile classes (see Glossary) by soil sampling and analysis.

(b) To establish, by laboratory leaching experiments, the likely effects of irrigating soils of the major soil profile classes with waters of a range of qualities which are likely to be available for irrigation.

(c) To establish Plant Available Water for the major mapped soil profile classes by calculation using the relationships derived by Shaw and Yule (1978).

2. PHYSICAL ENVIRONMENT

2.1 Climate

2.1.1 Rainfall

Average monthly and annual rainfalls for Murgon, Wondai and Mondure are set out in Table 1 while Table 2 shows the probabilities that Murgon will receive more than given amounts of rain.

TABLE 1

Average monthly and annual rainfall for selected stations (mm)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Murgon*	122	112	83	48	39	47	40	29	38	68	80	114	820
Wondai*	121	101	78	43	36	47	39	29	41	69	79	118	801
Mondure+	97	114	82	43	37	37	39	32	35	76	83	95	770

* Bureau of Meteorology

\+ Mean of 34 years, L. Russell (personal communication)

TABLE 2*

Rainfall probabilities for Murgon

Monthly and annual values (mm) likely to be equalled or exceeded in 10, 50 and 90% of occurrences.

Prob. (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
10	217	214	215	94	84	92	72	66	82	122	161	244	1168
50	97	98	86	43	37	24	31	20	25	64	76	94	787
90	29	22	8	8	5	5	3	5	5	15	21	23	532

* Bureau of Meteorology, from 1931 - 1970 data.

The rainfall is strongly summer dominant. From Table 1 it may be seen that Mondure, the source of rainfall data closest to the area investigated, receives 70% of its average annual rainfall in the six months October to March. Thunder can be expected on thirty days of the year, generally in the October to March period so that high intensity storm rains are frequent at this time.

2.1.2 Temperature

Kingaroy and Gayndah are the centres closest to the area studied for which temperature data is available. The area is intermediate in altitude and latitude so the temperatures should likely lie between those of these two centres set out in Table 3. The area experiences warm to hot summers with mild winter days and cold winter nights. Frosts may occur between mid May and mid September.

TABLE 3

Air temperatures, Kingaroy and Gayndah (°C)

Month	Kingaroy				Gayndah			
	Av. Max	Av. Min	Av. Mean	Av. Number of Days With Minimum <2.2°	Av. Max	Av. Min	Av. Mean	Av. Number of Days With Minimum <2.2°
Jan	28.7	16.1	27.4		32.8	19.4	26.1	
Feb	28.6	17.2	22.9		32.1	19.2	25.6	
March	27.1	15.7	21.4		30.7	17.1	23.9	
April	25.0	11.3	18.2	1	28.7	13.4	21.0	
May	21.4	6.7	14.1	7	25.3	9.2	17.3	2
June	18.8	4.1	11.6	9	22.5	6.9	14.7	6
July	18.5	3.4	10.9	16	22.1	5.4	13.7	8
August	19.9	3.6	11.7	16	23.8	5.8	14.8	2
Sept	22.9	6.9	14.9	3	26.9	9.3	18.1	1
Oct	26.1	10.8	18.4		29.8	13.4	21.6	
Nov	28.3	13.7	20.9		31.8	16.4	24.1	
Dec	29.9	15.6	22.8		32.7	18.4	25.6	
Year	24.7	10.7	17.7	52	28.3	12.8	20.6	19

2.2 Geology and Geomorphology

The area studied falls within that covered by the geology map of Hill, Tweedale and Skerman (1955) and the geology map and report of Murphy *et al.* (1976). It consists almost entirely of fine textured alluvium deposited by Barambah Creek and a number of tributary gullies that discharge onto the area. Small occurrences of coarser textured alluvium within and at the edges of the mapped area were noted in the soil survey. Murphy *et al.* (1976) give the age of the alluvium as Pleistocene to Holocene. As flooding is frequent and as abandoned creek channels and anabranches can be identified, it is likely that deposition is still occurring. Murphy *et al.* (1976) show the area from which the alluvium has arisen as complex but large areas of basalts, granites and sedimentary formations occur.

The area under study is bounded by a range of older mostly sedimentary geological formations. While Hill, Tweedale and Skerman (1955) show the southern boundary as the Mondure fresh water sedimentary beds of the Triassic Period, Murphy *et al.* (1976) map this area as Tertiary volcanics and Quaternary alluvium. The small areas of coarser alluvium noted may be related to one of the surrounding sedimentary formations.

2.3 Physiography

2.3.1 General

The area of this study has been broken into two landscape units. The first, designated Higher Alluvia, is the coarser textured alluvium noted in section 2.2 which generally lies from 1 to 4 m above the adjacent fine textured alluvium. The latter has been designated Lower Alluvia and occupies over 98% of the area.

The relationships between the soil profile classes identified in the survey, their physiography and their landscape positions are summarized in Table 4.

TABLE 4

Major distinguishing morphological and physiographic features of the soils

Soil Profile Class	Major Distinguishing Features	Soil Group	Physiography	Landscape Position
Wheatlands	Red and brown gradational and duplex soils with sandy clay loam to clay loam sandy A horizon.	Alkaline and neutral red and brown gradational and duplex soils	Higher Alluvia	Slightly elevated areas
Tregear	Yellow mottled grey duplex soils with sandy loam to sandy clay loam A horizon 15 to 45 cm deep and alkaline soil reaction trend.	Solodized solonetz		
Terrace	Dark hard setting sandy clays with neutral soil reaction trend.	Non-cracking clays	Lower Alluvia	Minor terraces and banks of Barambah Creek below main levee level
Weir	Whole coloured dark hard setting to weakly self mulching light to light medium clays with brown clay subsoils strongly alkaline by 90-120 cm.	Black earths		Levees of present and former creek channels
Byee	Whole coloured dark moderately self mulching clays with brown clay subsoils strongly alkaline by 90-120 cm.	Black earths		Intermediate positions, often associated with drainage lines from the surrounding hills
Eastgate	Whole coloured dark and brown weakly self mulching to hard setting light medium to medium clays with brown clay subsoils, strongly alkaline by 30-60 cm.	Black earths and brown clays		Intermediate positions, often levee backslopes
Gueena	Brown mottled grey moderately self mulching medium clays with grey clay subsoils, strongly alkaline by 90-150 cm.	Grey clays		Low-lying positions, levee backswamps and broad drainage lines
Kaber	Brown weakly self mulching light medium clays with brown clay subsoils, strongly alkaline by 60-90 cm, moderate to large amounts iron-manganese concretions above 30 cm.	Brown clays		Intermediate positions apparently receiving wash from hills immediately adjacent

2.3.2 *Higher Alluvia*

This slightly elevated unit is occupied by two soil profile classes: Wheatlands, alkaline and neutral red and brown gradational and duplex soils, and Tregear, grey solodized solonetz soils. Both soil profile classes have A horizons of coarse or medium texture, generally sandy, and D horizons of sandy medium or fine texture, frequently containing subangular gravel.

2.3.3 *Lower Alluvia*

The plains of low relief of this unit are occupied by fine textured soils associated with Quaternary alluvium. Minor terraces and banks below the main levee level of Barambah Creek are occupied by the hard setting sandy clay soils of the Terrace soil profile class while levees of the present and former creek channels are occupied by the black earths of the Weir soil profile class. Black earths of the Byee soil profile class occur in intermediate positions often associated with drainage lines from the surrounding hills. The black earths and brown clays of the Eastgate soil profile class are associated with other intermediate positions, often levee backslopes. Areas apparently receiving fine textured wash containing large amounts of iron-manganese concretions from the hills immediately adjacent are occupied by brown clays of Kaber soil profile class. Mottled grey clays of Gueena soil profile class occur in low-lying areas, levee backswamps and broad drainage lines.

2.4 Natural Vegetation

Most of the area investigated has been cleared for cropping and grazing and it is likely that the grass species composition in the uncleared areas has been drastically altered by grazing and burning. Notes on vegetation on the soil profile classes identified in the survey were made wherever possible and Table 5 gives the most common structural form (Specht 1970) and species composition for each.

The most common structural form is the open forest and the most common tree species is blue gum. It appears to have been dominant on Wheatlands, Tregear, Terrace, Weir, Byee, Kaber and Gueena soil profile classes while gum topped box or poplar box appear to have been dominant on Eastgate areas. Broad leaved ironbark is associated with blue gum on a number of soil profile classes while rough barked apple is an associate species on the Weir soil profile class.

In the uncultivated state, most soil profile classes carry a moderately developed grass layer of blue grasses. Introduced grass species common in the area include rhodes grass, paspalum, barnyard grass and couch.

2.5 Hydrology

2.5.1 Surface Hydrology

The area is drained by a series of levee backswamps and broad drainage lines that often follow the bases of the surrounding hills. This system enters Barambah Creek or an anabranch of it through natural gullies eroded through the levee or, in two cases, through channels dug in the levee. Drainage from the broad drainage lines is very slow and water can still be entering the creek up to 14 days after periods of heavy rainfall. Permanent and semi-permanent lagoons occur in these drainage lines.

As well as rainfall within the area, the drainage system must cope with runoff from the surrounding hills and over-bank flood flows from Barambah Creek. Numerous unnamed gullies and minor creeks leave the surrounding hills to lose their identity in the broad drainage lines of the flats surveyed. The only streams to make direct confluence with Barambah Creek within the surveyed area are Oakey Creek in the east and an unnamed gully below "Marshlands" homestead in the west. No records of the frequency of over-bank flow from Barambah Creek are available but it appears that flood flows occur more often than once every two years. The creek can remain at flood levels for periods of a few hours to several days.

2.5.2 Subsurface Hydrology

Little data is presently available on the subsurface hydrology of the area. A number of bores have been sunk for irrigation purposes and the Queensland Water Resources Commission have sunk a number of test holes. Much of the area is underlain by ground water of variable quality. A number of bores, many close to the surrounding hills, have been sunk for irrigation then abandoned due to poor quality water. Many bores have, however, been used successfully for irrigation for a number of years.

It appears that the ground water surface is about 6 to 10 m below ground level at the eastern end of the area and 4 to 8 m below ground level at the western end (Queensland Water Resources Commission unpublished data). Ground water levels above Silverleaf Weir rose significantly when the weir was completed. Seepages are observed from the banks of Barambah Creek below the usual water line in times of low flow so it appears that the ground water system has connections with the creek.

Murphy and Easton (1950) note that ring-barking of timber on the hills to the east of the area in the period 1877 to 1890 immediately caused many springs to develop and saline seepages are now features of valleys leading onto the surveyed area. These are prominent in the Merlwood, Barlil and Mount McEuen areas. It is likely that these seepages, the runoff from which soaks away before reaching the flats, provide an input of saline waters to the ground water system underlying the flats. Water from one of these seepages was found to have an electrical conductivity of 4600 $\mu S\ cm^{-1}$.

3. SOIL SURVEY METHOD

3.1 General

Five controlled traverses were run in the area to be surveyed and 34 sites on these traverses were selected for profile descriptions on the basis of photopattern and landscape position. Soils were exposed to 150 cm by augering or with 5 cm diameter thin walled tubes and classified according to the Factual Key of Northcote (1971). Profile characteristics not included in this classification were also recorded and used as necessary when formulating soil groups. Soil structural descriptions were made on the 5 cm diameter cores. The profile descriptions obtained were grouped into eight soil profile classes which were used as a reference to map the area at 1:50 000 on 1:25 000 colour air photographs. Mapping was by free survey and a further 171 recorded ground observations of sufficient detail to identify soil profile classes were made. Air photo interpretation was used as an aid in locating many boundaries.

3.2 Soil Profile Class Derivation

The basic soil grouping used is the soil profile class. The soil profile classes were obtained by grouping profiles of similar morphology so the system is an ascending one commencing from observed soil properties. Variation in characteristic soil morphological properties is less within classes than between classes. In grouping soil profiles into soil profile classes, emphasis has been given to those characteristics considered likely to have greatest significance for irrigated land use. All soil profile classes have been named and, where possible, the names indicate a locality where the soil profile class has been mapped.

3.3 Mapping Unit Derivation

Simple mapping units are used and in most cases one soil profile class occupies greater than 60% of a mapping unit. Mapping units are identified by the name of the dominant soil profile class, an abbreviation of which appears in the actual mapped areas. Ground observation density was insufficient to identify the proportion of associated and minor soil profile classes in most units.

TABLE 5

A description of the morphology, physiography and vegetation of the soil profile classes

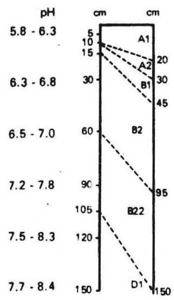
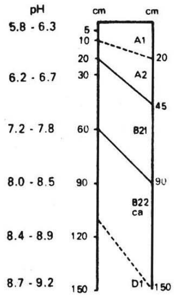
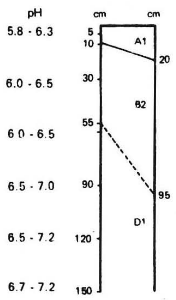
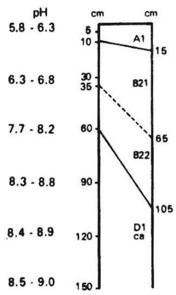
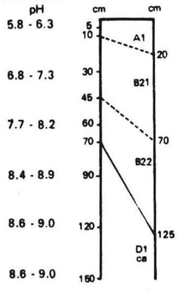
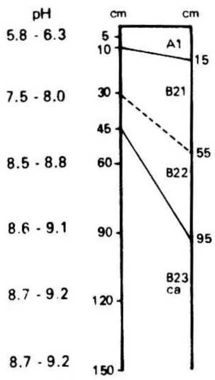
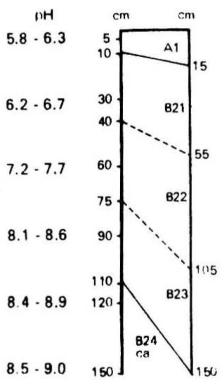
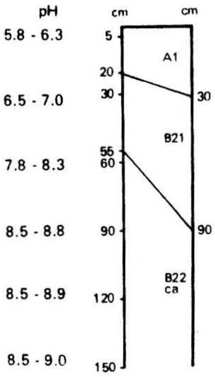
Soil Profile Class	P.P.F(s)	Soil Profile Class Description*	Physiography	Natural Vegetation
Wheatlands	Gn3.16 Gn3.26 Dr2.22 Gn3.13 Dr3.33 Gn3.25 Gn3.19 Db1.33	Alkaline and Neutral Red and Brown Gradational and Duplex Soils:  A_1 Brown (7.5YR 3/3, 4/3) sandy clay loam to clay loam sandy, massive, dry slightly hard to hard, occasionally manganiferous concretions and veins. A_2 As above, but brown to yellow-brown (7.5YR 4/4, 5/6) and occasionally sporadically bleached. B_1 Red-brown to brown (5YR, 7.5YR 3/6, 4/4, 4/6) sandy clay to light clay, moderate medium blocky, dry hard, frequently manganiferous concretions and veins. B_{21} Frequently moderately mottled red-brown to brown (5YR, 7.5YR 3/6, 4/4, 4/6) medium clay, strong medium blocky, dry hard, frequently manganiferous concretions and veins. B_{22} As above but always has manganiferous concretions and veins. D_1 As above but sandy clay loam to clay loam sandy frequently with subangular gravel.	Higher Alluvia Slightly elevated areas. 1-4% slope	Open forest of blue gum and broad leaved ironbark. Moderately developed grass layer of blue grasses.
Tregear	Dy3.43 Dy3.33	Solodized Solonetz:  A_1 Dark (7.5YR, 10YR 3/2) sandy loam to sandy clay loam, massive, dry hard. A_2 Grey (10YR 5/2) sandy loam to sandy clay loam, massive, dry slightly hard, manganiferous concretions, conspicuously bleached, occasionally sporadically bleached. B_{21} Strongly yellow mottled grey to yellow brown (10YR 5/2, 5/3, 5/4) medium heavy clay, strong medium columnar, dry extremely hard, manganiferous concretions and veins. B_{22}ca As above but strong medium lenticular and concretionary lime. D_1 Brown (7.5YR, 10YR 4/3) sandy clay, frequently with subangular gravel, moderate medium blocky, dry very hard, manganiferous concretions and veins, concretionary lime.	Higher alluvia. Slightly elevated areas. 1-3% slope	Woodland of blue gum and broad leaved ironbark. Moderately developed grass layer of blue grasses and love grasses.
Terrace	Uf6.32 Ug5.15	Non-Cracking Clays:  A_1 Dark (10YR, 2.5Y 3/1, 3/2) sandy clay, strong fine blocky, dry very hard. B_2 Dark (10YR 2/3, 3/2) light medium clay to medium clay, strong fine blocky, dry very hard. D_1 Brown (7.5YR, 10YR 3/3, 4/3, 4/4) sandy clay, moderate medium blocky, dry hard.	Lower alluvia. Minor terraces and banks of Barambah Creek below main levee level. 1-10% slope.	Open forest of blue gum, rough barked apple and broad leaved ironbark. Some red bottlebrush occurs. Moderately developed grass layer of blue grasses.
Weir	Ug 5.15 Ug 3.1	Black Earths:  A_1 Hard setting to weakly self mulching surface on dark (10YR 2/1, 2/2, 3/1, 3/2) light clay to light medium clay, strong fine blocky, dry hard. B_{21} Dark (10YR 2/1, 2/2, 3/1, 3/2) medium clay, strong medium blocky, dry very hard. B_{22} As above with strong medium lenticular structure and occasionally manganiferous concretions. D_1ca Brown (7.5YR, 10YR 3/3, 3/4, 4/3, 4/4) light medium clay, strong fine to medium blocky, dry very hard, manganiferous concretions, concretionary lime. Variant: A sporadic bleach occasionally occurs towards the base of the A horizon in uncultivated situations.	Lower alluvia. Levee of present and former creek channels. 0.5-2% slope.	Open forest of blue gum, rough-barked apple and broad leaved ironbark.
Byee	Ug 5.15	Black Earths:  A_1 Moderately self mulching surface on dark (10YR 2/1, 2/2, 3/1, 3/2) medium clay to medium heavy clay, strong fine blocky, dry very hard. B_{21} As above with strong medium blocky. B_{22} As above with strong medium lenticular, frequently manganiferous concretions. D_1ca Brown (7.5YR, 10YR 2/3, 3/3, 4/3, 4/4) medium clay to medium heavy clay, strong medium blocky, dry very hard, manganiferous concretions, concretionary lime. Variant: D_1ca horizon grey (10YR 4/2)	Lower alluvia. Intermediate positions, often associated with drainage lines from the surrounding hills. 0.5-1% slope.	Open forest of blue gum. Well developed grass layer of blue grasses.

TABLE 5 (cont'd)

Soil Profile Class	P.P.F(s)	Soil Profile Class Description*	Physiography	Natural Vegetation
Eastgate	Ug5.15 Ug5.34 Ug3.3	Black Earths and Brown Clays: Weak beta nuram gilgai occasionally evident in uncultivated situations, mound and depression have similar morphology.  A_1 Weakly self mulching to hard setting surface on dark (7.5YR, 10YR 2/1, 2/2, 3/1, 3/2) light medium clay to medium clay, strong fine to medium blocky, dry very hard, manganiferous concretions. B_{21} Brown (10YR 3/3, 4/3) to dark (7.5YR, 10YR 2/1, 2/2, 3/1, 3/2) medium clay to medium heavy clay, strong medium blocky, dry very hard to extremely hard, manganiferous concretions. B_{22} As above but frequently strong fine to medium lenticular. B_{23}ca Brown (7.5YR 3/3, 3/4, 4/3, 4/4, 4/6) light medium clay to medium clay, moderate to strong fine to medium blocky, dry hard to very hard, manganiferous concretions, concretionary lime. Variant: A sporadic bleach occasionally occurs towards the base of the A horizon in uncultivated situations.	Lower alluvia. Intermediate positions, often levee backslopes. 0-1.5% slope.	Open forest to woodland of gum-topped box and poplar box with occasional blue gum.
Gueena	Ug5.24 Ug5.28	Grey Clays: Weak to moderate beta nuram gilgai evident in uncultivated situations, mound and depression have similar morphology.  A_1 Moderately self mulching surface on moderately mottled dark (10YR 2/1, 2/2, 3/1, 3/2) medium clay, strong medium blocky, dry very hard, manganiferous concretions. B_{21} Moderately brown mottled grey (10YR, 2.5Y 4/1, 4/2, 5/2) medium clay to medium heavy clay, strong fine to medium blocky, dry very hard, manganiferous concretions. B_{22} As above but strong medium lenticular. B_{23} As above but only occasionally moderately mottled. B_{24}ca Grey (10YR, 2.5Y 4/1, 4/2) or occasionally brown (10YR 4/3) medium clay to medium heavy clay, strong fine blocky, dry very hard, manganiferous concretions, concretionary lime.	Lower alluvia. Low-lying positions, levee backswamps and broad drainage lines. 0-1% slope.	Open forest of blue gum. Moderately developed grass layer of blue grasses.
Kaber	Ug5.34	Brown Clays:  A_1 Weakly self mulching surface on brown (7.5YR, 10YR 3/3, 4/3) light clay to light medium clay, moderate fine blocky, dry hard to very hard, iron-manganese concretions. B_{21} Brown (7.5YR, 10YR 3/3, 4/3, 4/4) medium clay to medium heavy clay, strong medium blocky, dry very hard, manganiferous concretions. B_{22}ca As above but frequently mottled and with concretionary lime. Variant: A dark (10YR 3/1, 3/2) medium clay D horizon may occur below 90 cm.	Lower alluvia. Intermediate positions apparently receiving wash from hills immediately adjacent. 0.5-1.5% slope.	Open forest of blue gum and broad leaved iron-bark.

* ——— abrupt or clear boundaries - - - - gradual or diffuse boundaries

Other conventions used in this Table are given in Appendix 5.

4. SOILS - MORPHOLOGY AND MAPPING

4.1 Relationship to Physiography and Landscape Position

The relationship of the soil profile classes to physiography and landscape position is summarized in Table 4. As discussed in section 2.3 soils of the lower alluvia are predominantly clays while coarser textured gradational and duplex soils occur on the higher alluvia. Figure 2 shows a landscape section across the area on which the relative positions of the most important soil profile classes in terms of area are illustrated.

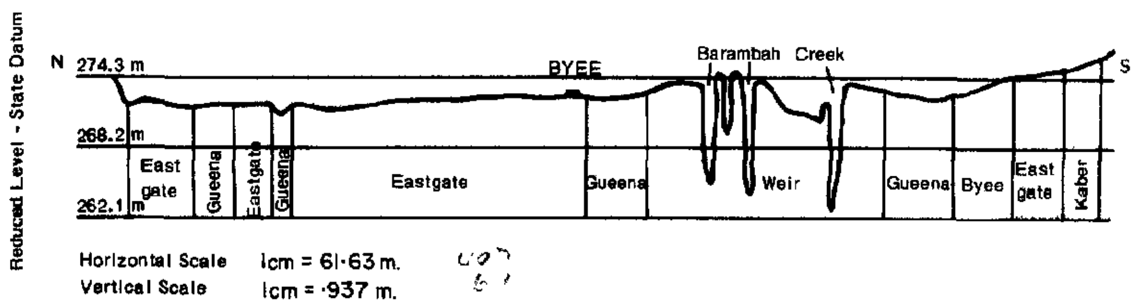


Figure 2 Landscape section of Byee area along road north from Wheatlands school showing relative positions of mapping units.

4.2 Morphology

Table 5 gives detailed morphological descriptions of the soil profile classes and the range of variation within them. Horizon notation follows McDonald (1977).

4.3 Soil Variability

The mapping units, named for the dominant soil profile class, their area, the approximate percentage of that soil profile class, and the associate soil profile classes are set out in Table 6. The dominant and associate soil profile classes together occupy at least 80% of the mapping unit area.

TABLE 6

Mapping unit composition

Mapping Unit and Dominant Soil Profile Class	Percentage of Dominant Soil Profile Class	Associate Soil Profile Classes	Minor Soil Profile Classes	Mapped Area (hectares)
Wheatlands	80		Eastgate	62
Tregear	80		Eastgate	37
Terrace	90		Weir	3
Weir	60	Eastgate Gueena	Terrace Byee	2055
Byee	70	Eastgate	Weir Gueena	783
Eastgate	70	Gueena Weir	Byee	1225
Gueena	70	Eastgate Weir	Byee	1937
Kaber	90		Eastgate	17

5. SOILS - CHEMICAL AND PHYSICAL CHARACTERISTICS

5.1 Soil Sampling

Nine sites in the survey area were sampled for detailed chemical and physical analysis and the results, together with the profile descriptions, are presented in Appendix 1. Appendix 3 gives methods of analysis while Appendix 4 gives some guidelines for the interpretation of results. The profiles were sampled to 150 cm in 10 cm increments and a bulk of ten 0 to 10 cm surface samples from a 10 m-diameter circle surrounding the site was also collected.

One uncultivated and one cultivated site was sampled on each of the four soil profile classes occupying the greatest area (Weir, Byee, Eastgate and Gueena) and one cultivated site was sampled from the Wheatlands soil profile class. The last site mentioned was on the Higher Alluvia landscape unit while the others were from the Lower Alluvia unit. The locations of these sites together with those of sites sampled for salinity appraisal only are shown on the accompanying soils map.

5.2 pH

All surface (0-10 cm) soils are in the neutral range (pH 6.5 - 6.8).

The mean pH trend (Figure 3) with depth is for all soils to become moderately to strongly alkaline (pH range 8.1 - 8.8) by 150 cm. Gueena subsoils are only moderately alkaline to 1 m.

Eastgate subsoils are the most strongly alkaline. A maximum pH value of 9.4 was recorded at 100 cm for the Eastgate site 8.

5.3 Salinity

5.3.1 Current Salinity Status

A plot of chloride profile trends as shown in Figure 4 indicates the degree of salinity of the soils.

Apart from some sites which are affected by saline seepages the chloride values (1:5 soil water suspension of all soils to 1.5 m) are less than 0.2% Cl and would thus be classified as non saline (Northcote and Skene 1972).

The only soils that exceed .06% chloride in the upper metre of the profile are some Gueena soils where this occurs at around 80 - 100 cm.

The Weir and Byee soils have chloride levels in the upper 60 cm of less than .03% which are the lowest chloride levels of all groups to this depth.

Three areas of high salinity were located -

(i) the north east section, adjacent to the surrounding uplands, in the vicinity of sample sites 8, 18, 19, 20, 22 where large saline seepages flow towards the flats.

(ii) the southern section near site 24, also adjacent to surrounding uplands.

and (iii) an area on Barambah Creek, near sites 6 and 29.

Electrical conductivity (EC) values follow the same trend as chloride, suggesting little or no contribution from other salts such as gypsum.

In all three high salinity areas EC was in the range 0.9 - 1.7 mS cm^{-1}, roughly equivalent to an EC of 6 - 11 mS cm^{-1} on the saturation extract using the conversion of Talsma (1968).

5.3.2 Salinity Changes with Time

Changes in soil salinity with time reflect changes in hydrology or climate. A rise in water table levels will result in increased soil salinity whereas flooding will tend to reduce soil salinity. A previous sampling gave an opportunity to evaluate any soil salinity changes with time and thus predict likely adverse effects which may be occurring.

Two transects across the Byee area were made in March 1970 (B.J. Crack unpublished data). The major transect was sampled adjacent to the QWRC bore hole transect. Several of these sites were resampled in December 1978 to determine any changes in salinity. The sites resampled in

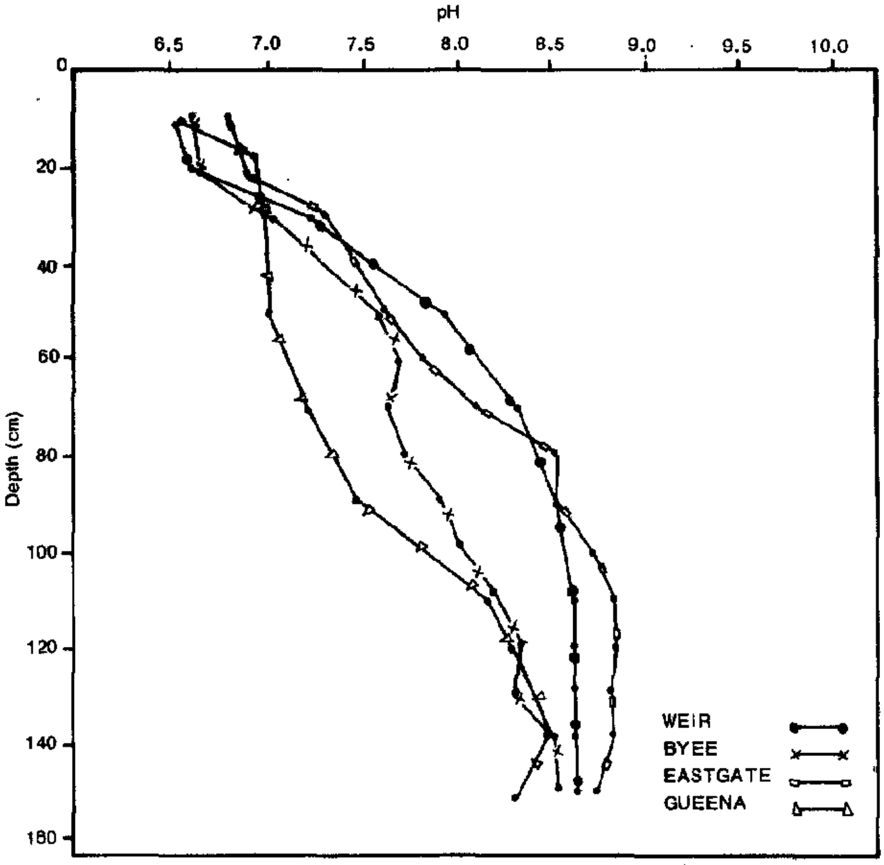


Figure 3 Soil pH profiles.

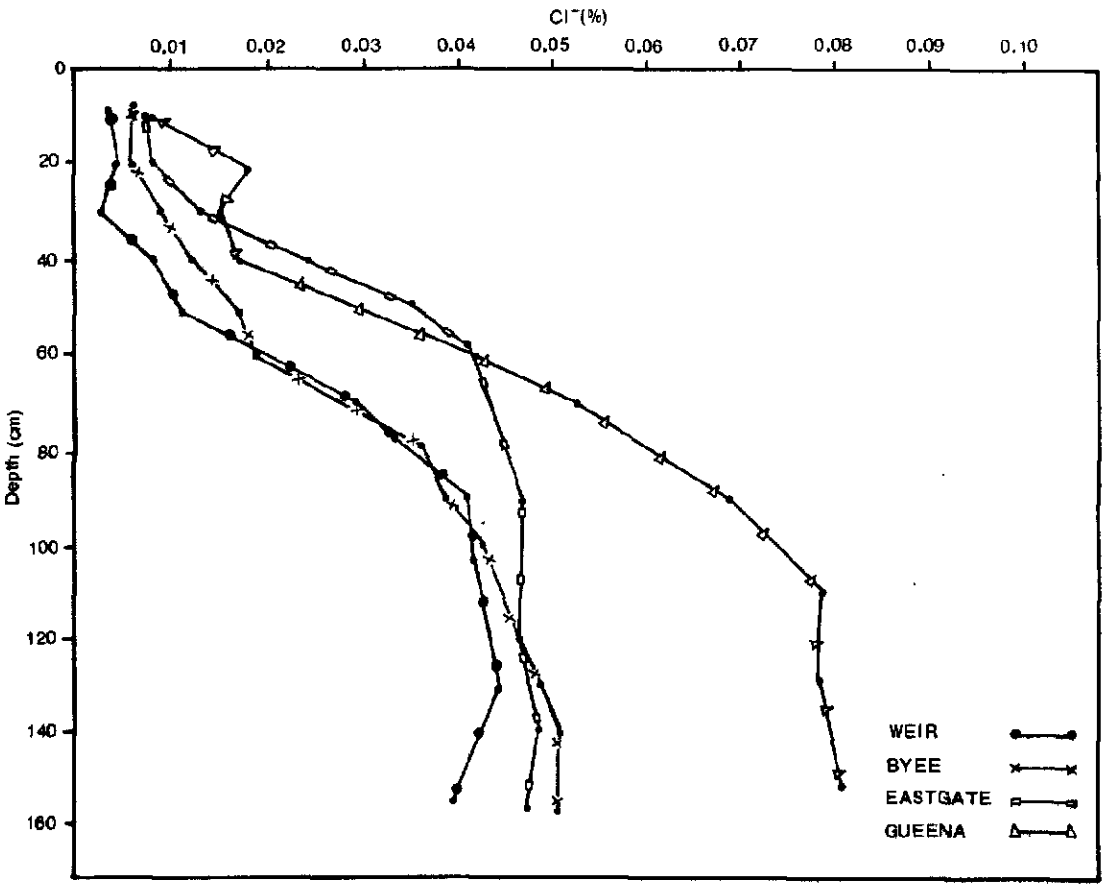


Figure 4 Chloride profiles.

1978 for comparison with the 1970 sites are shown on the attached map as sites 11, 12, 13, 1, 14, 15, 18, 28. Table 7 lists the sites, QWRC bore number, soil profile class and salinity data.

TABLE 7

Changes in soil salinity 1970 - 1978

Site No.	QWRC Bore No.	Soil Profile Class	Changes in Electrical Conductivity and Chloride	EC at 1 metre $\mu S\ cm^{-1}$ 1970	1978	Comments	Importance
11	B12	Kaber	decrease all depths-most significant decrease 50-120 cm, peak below 150cm	750	350	the 1970 site in paddock may have been irrigated	some leaching is suggested.
12	B11	Eastgate	no significant change to 120cm with decrease of 400 μScm^{-1} at 150 cm, current peak at 110 cm.	700	700	possibility of 1979 sampling being different soil profile class nearer Gueena	high pH indicates ESP of around 25% from 90 cm with restricted leaching (see sodicity sect. 5.4).
13	B10	Eastgate	slight increase in EC below 40 cm, slight decrease in Cl below 50, peak below 150 cm.	600	625		no significant change.
1	B9	Weir	slight decrease to 60, slight increase below, peak at 70 cm.	320	420		no significant change, perhaps slight leaching of 0-50 cm.
14	B2	Eastgate	no change, uniformly very low throughout, no peaks.	50	50	soil is the low salinity end of the range within Eastgate.	no change.
15	B4	Eastgate	large decrease both EC and chloride all depths, peaks moved from 60cm to 90cm.	650	320		some leaching is indicated or different soil.
18	B7	Eastgate	little change to 50 cm then large increase to 150 cm.	600	1100		large increase at depth suggests saline incursions. pH indicates high sodicity of about 25% ESP.
28		Eastgate	very slight decrease 20-50 cm, slight increase 60-90 cm then very slight decrease.	500	500	1970 sampling has been irrigated from the creek	small amount of leaching in the soil surface particularly.

There have been no large changes in salinity over most sites with the exception of site 18. This site is close to the area of saline seepage and there is a significant increase in salinity due to either high water table or saline incursions.

Over most of the area salinity is not expected to be a problem provided the water table remains below at least 2 - 3 metres (Talsma 1963).

5.4 Sodicity

Northcote and Skene use exchangeable sodium percentage (ESP) or sodicity to classify soils as below:-

(1) Non sodic less than 6

(2) Sodic 6 - 14

(3) Strongly sodic greater than 14

Mean trends in ESP with depth for all soils are shown in Figure 5.

The Eastgate soils are strongly sodic at 30 cm and reach a maximum ESP value of 27 at 150 cm.

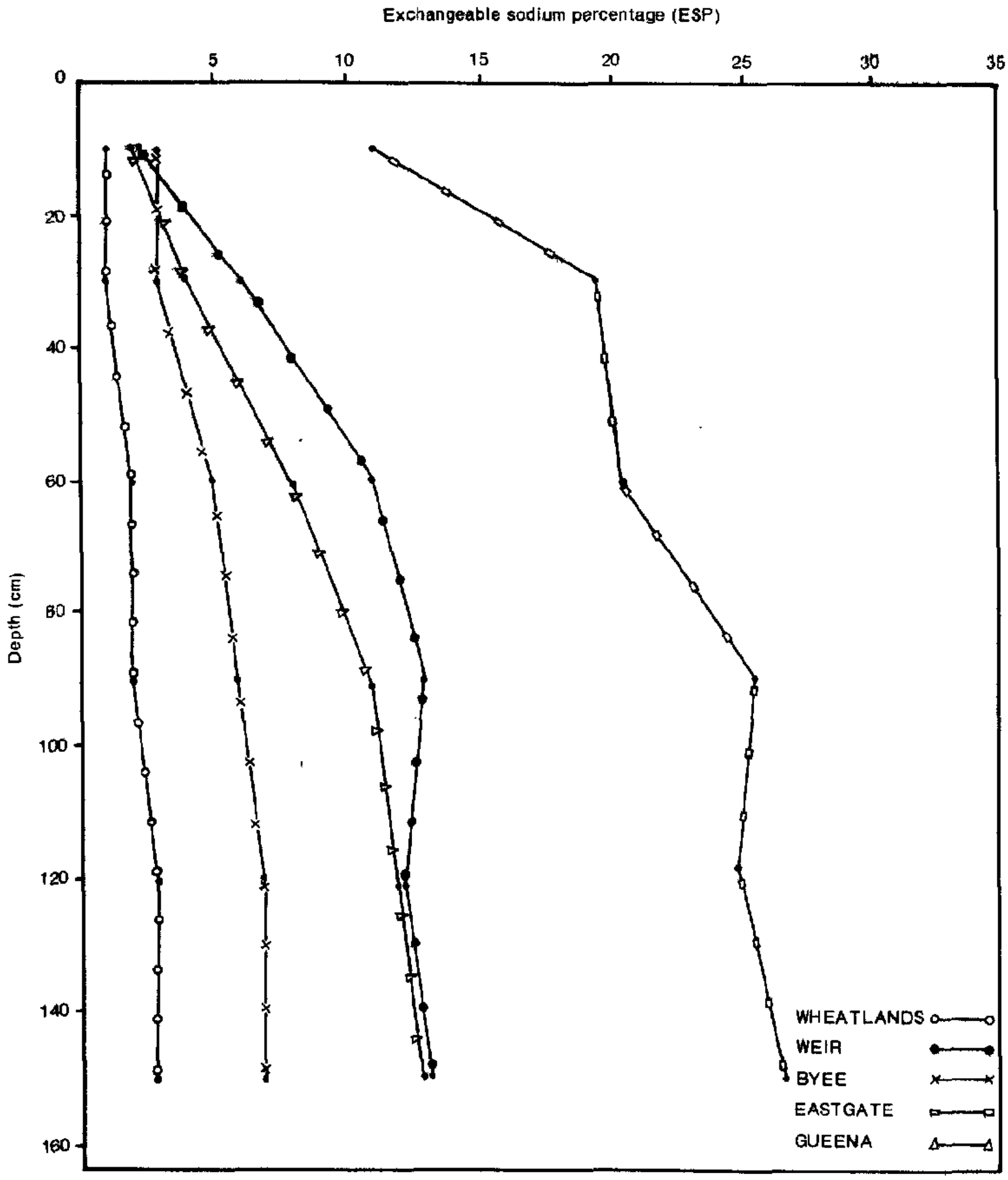


Figure 5 Exchangeable sodium percentage profiles.

No other soils in the area exceed an ESP of 14. However, Gueena and Weir are sodic at 60 cm with a maximum ESP for both soils of 13 at 90 cm. The Byee soils are just sodic at 90 cm but do not exceed an ESP of 7 at 150 cm. The Wheatlands soils are non-sodic.

5.5 Dispersion Ratio (R_1)

An indication of the dispersive characteristics of the soils is provided by the ratio R_1 (Appendix 3).

Table 8 lists the mean dispersion ratios R_1 at 0 - 10 cm and 50 - 60 cm depths for the soil groups analysed.

TABLE 8

Dispersion ratio (R_1) at 0-10 cm and 50-60 cm

Soil Profile Class Depth cm	Eastgate	Gueena	Byee	Weir	Wheatlands
0 - 10	.68	.37	.45	.40	.57
50 - 60	.91	.66	.46	.47	.30

The Eastgate soil is rated as moderate to high while the other soils do not exceed .66 at depth suggesting moderate to low dispersibility.

5.6 Particle Size Distribution

Clay contents for the profiles analysed are shown in Figure 6.

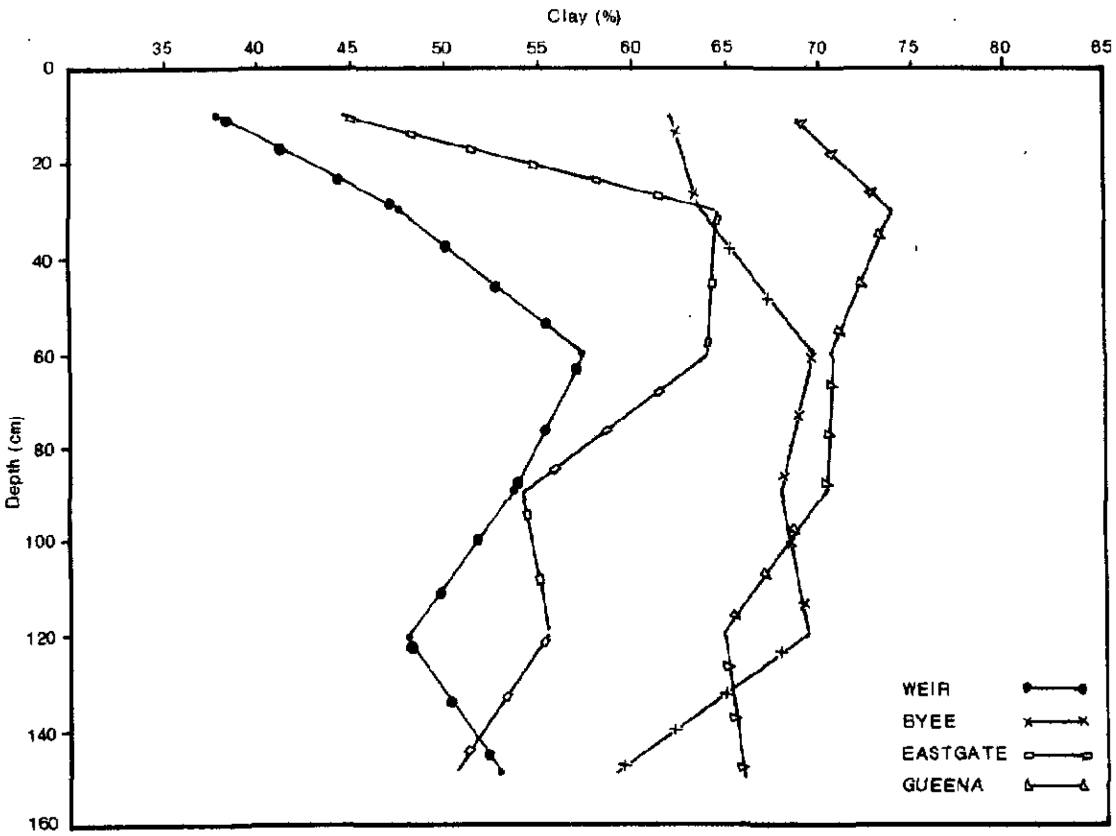


Figure 6 Clay content profiles.

Byee and Gueena have the highest levels of clay, exceeding 65% throughout most of the profile.

Eastgate and Weir have less clay in surface horizons, increase in the 30 - 60 cm zone and decrease below this depth. Variations in particle size distribution with depth in Eastgate, Weir and Wheatlands suggest the soils are layered.

Wheatlands soil usually has sandy field texture at the surface and in the deeper parts of the profile.

5.7 Cation Exchange Capacity (CEC)

Byee soils show the highest CEC with values of greater than 50 for most of the profile. CEC values greater than 40 characterize the Gueena and Eastgate soils while Weir soils have lower CEC ranging from 32 to 42.

5.8 Clay Activity Ratio

Clay Activity Ratio (CEC/Clay) m. equiv. per g. of clay, gives an indication of the clay mineralogy. Values do not vary greatly with depth. Ratios are in the range .7 to .8 indicating considerable amounts of montmorillonite present in the Weir, Gueena, Byee and Eastgate soils.

The far lower clay activity ratio (0.5) of Wheatlands indicates a substantially different clay mineralogy. The difference in clay activity ratio could indicate that the Wheatlands is an older soil with more weathered clay minerals or that it was formed on alluvium of different origins to that on which the clay soils were formed. The coarse sand content of the Wheatlands soil also indicates that it may have developed on an alluvium of different origins and supports the placement of it in a different landscape unit to the clay soils.

5.9 Exchangeable Calcium and Magnesium

Magnesium is the dominant cation in all soils except Weir and Wheatlands where calcium is dominant. Table 9 shows the exchangeable cations and saturation percentages for the soil groups at two selected depths.

Magnesium is the dominant cation in Eastgate, Gueena and Byee soils.

Emerson and Bakker (1973) suggested that a high magnesium to calcium ratio and ESP greater than 6 can promote clay dispersion. On this basis the Eastgate soils with magnesium to calcium ratios of 1.6 and ESP greater than 14 at 30 cm would rate as the poorest soils. This view is supported by the measurement of dispersion R_1 (see Appendix 3). R_1 ratios are high for the Eastgate soils being greater than .78 at 30 cm and reach a maximum level of .91 at 60 cm. These were the highest R_1 levels recorded.

Gueena and Byee also have high magnesium to calcium ratios (i.e. 1.4 to 1.6) but have ESP values of less than 7 in the upper metre of the profile.

TABLE 9

Exchangeable cations and saturation percentages at 0-10 cm and 50-60 cm depths

Soil Profile Class	Depth (cm)	Exch.† Ca	Ca* / CEC	Exch.† Mg	Mg* / CEC	Exch.† Na	Na* / CEC	C.E.C.†
Eastgate	0-10	7.6	21	12.7	35	3.8	11	36
	50-60	14.5	32	23.5	52	8.9	20	45
Gueena	0-10	17.0	33	23.0	47	1.0	2	51
	50-60	15.5	33	25.0	53	3.5	9	47
Byee	0-10	17.0	33	23.0	47	1.4	3	51
	50-60	20.0	36	27.5	49	2.8	5	56
Wheatlands	0-10	4.1	34	2.8	23	0.2	1	12
	50-60	8.9	39	7.2	31	0.5	2	23
Weir	0-10	11.5	36	10.4	33	0.8	2	32
	50-60	18.0	48	17.5	42	4.3	11	42

† m.e./100 g

* per cent

5.10 Fertility

Table 10 sets out relevant soil fertility data for the 0-10 cm depth increment of the sites sampled (see 5.1). The results indicate that the soils of the area are of moderate to high fertility.

5.10.1 Phosphorus

Available phosphorus levels are high at all sites except the uncultivated Byee and uncultivated Gueena sites where they are only fair. Phosphate fertilizers are not regularly applied and it is doubtful if these differences between the uncultivated and cultivated sites can be attributed to fertilizer addition. The differences may be associated with increased nutrient recycling in the cultivated soils.

It appears unlikely that phosphorus fertilizer applications will be necessary over the bulk of the area but they could be required on some areas of Byee and Gueena soils.

TABLE 10

Soil fertility data for sampled sites, 0 to 10cm depth

Soil Profile Class	Wheatlands	Weir		Byee		Eastgate		Gueena	
Site number and condition	7 Cultivated	1 Uncultivated	2 Cultivated	4 Uncultivated	10 Cultivated	8 Uncultivated	6 Cultivated	9 Uncultivated	5 Cultivated
% Organic* C	0.66	2.9	2.2	2.2	1.6	3.0	1.4	2.9	1.7
% Total* N	0.06	0.10	.16	0.20	.13	.23	.13	.25	.19
C to N Ratio	11	29	14	11	12	13	11	11	9
ppm Acid Extr. P	110	120	120	17	120	85	53	28	35
ppm Bicarb Extr. P	86	100	100	26	100	100	42	29	61
m. eq% Repl. K	.80	.72	.39	.26	.61	.45	.26	.46	.50
m. eq% *‡ Exch. Ca^{++}	4.1	13	11	21	10	5.3	10	18	16
m. eq% *‡ Exch. Mg^{++}	2.8	11	10	33	14	8.3	17	25	21
ppm DTPA Extr. Fe	30	120	84	80	88	120	50	90	96
ppm DTPA Extr. Mn	50	77	50	58	63	66	52	60	57
ppm DTPA Extr. Cu	1.2	2.8	2.0	3.8	3.0	1.8	2.6	3.6	3.2
ppm DTPA Extr. Zn	0.7	5.2	2.2	1.6	1.0	2.0	0.6	1.3	1.0

* Oven dry basis, all others air dry

‡ Profile sample, all others from bulk sample

5.10.2 Organic Carbon and Total Nitrogen

Organic carbon (uncorrected Walkley and Black) levels are medium to low while total nitrogen levels are low to very fair. Levels of both are generally lower at cultivated sites than at uncultivated sites indicating a decline in soil organic matter and nitrogen has occurred under cropping. As nitrogen fertilizers are now widely used for gramineous crops and the return of crop residues is increasing, this decline may halt.

The carbon:nitrogen ratios range between 10 and 14.

5.10.3 Potassium, Calcium and Magnesium

Table 10 shows that the surface (0-10 cm) samples of all soils were above 0.2 m. equiv. per 100 g which is often used as a critical value for potassium (Williams and Lipsett 1950, Piper and De Vries 1960).

The potassium levels in the analysed depth increments below the surface are around 0.2 m. equiv. per 100 g for the majority of soils which is fair to low, (Appendix 1).

The calcium and magnesium status of the sampled sites appears adequate.

5.10.4 Iron, Manganese, Copper and Zinc

Levels of iron, manganese and copper at all sampled sites are well above those considered adequate by Viets and Lindsay (1973).

Zinc levels are regarded as marginal (Viets and Lindsay 1973) in the Wheatlands and cultivated Eastgate soils. Occurrence of zinc deficiencies on these soils is a distinct possibility. The rest of the soils have adequate zinc levels.

Trace element toxicities are unlikely.

6. SOIL WATER RELATIONSHIPS

Soils differ in the amount of water which can be stored and subsequently made available to the plant before the plant becomes stressed from lack of water. This measure of plant available water is an important aspect of soil suitability for irrigation. To be useful for irrigation scheduling this amount of water is expressed as a volume of available water.

There are 3 aspects to the determination of the volume of available water -

(a) measurement or prediction of the upper (W_{max}) and lower (W_{min}) gravimetric water contents for individual depth increments.

(b) selection of an appropriate bulk density to convert the gravimetric water contents to a volume of water.

(c) estimation of a realistic crop rooting depth below which only small amounts of water are available to the plant.

It is well recognised that the laboratory determined upper water content ($-^1/_3$ bar) may be very different from the field measurement due to the large effect of soil structure at this soil water potential, (Salter and Williams 1965, Gardner 1971). Rate of wetting and overburden also greatly affect the laboratory measurement. To overcome these limitations, Shaw and Yule (1978) found a relationship between the field measured upper (W_{max}) and lower (W_{min}) soil water contents for Emerald soils (under irrigated sorghum) and cation exchange capacity or -15 bar water content. The highly significant relationship with -15 bar water content (R^2 >0.92) allows good prediction of W_{max} and W_{min}. Shaw and Yule (1978) also found that bulk density at W_{max} could be used in calculation to give a reliable estimate of the volume of soil water and that rooting depth could be predicted from the pattern of accumulation of chloride in the profile.

Before applying the predictions an experiment was conducted at two sites in the Byee area to compare field measurements of Plant Available Water with the calculated values.

Two soil profile classes were chosen, Weir and Gueena, and a 60 cm diameter ring was inserted 5 cm into the soil at one site on each soil. Water was ponded in the ring for 44 hours during which 188 cm entered Gueena and 130 cm entered Weir. Twenty four hours after cessation of ponding 3 soil cores to 150 cm were taken within the area of the ring for soil water content. Two soil cores were taken in the vicinity of the rings prior to ponding to obtain the dry profile.

Electrical conductivity, chloride, and $-^1/_3$ and -15 bar soil water content determinations were made at each site.

(a) Prediction of W_{max} and W_{min}

The mean pre-ponding and the wettest post-ponding soil water profiles are shown in Figure 7 for the 2 soils together with the laboratory $-^1/_3$ bar and -15 bar water contents and the predicted W_{max} and W_{min} water contents. The variability was low for all but the wetting profiles of Gueena site which is possibly a reflection of the extensive soil cracking. Both sites were quite dry at the time of the experiment (January 1979) and the pre ponding soil water contents approximate the -15 bar. The soils were well cracked to 60-70 cm in the soil cores taken. The depth of wetting was 70 cm in Weir and 130 cm in Gueena, Figure 7.

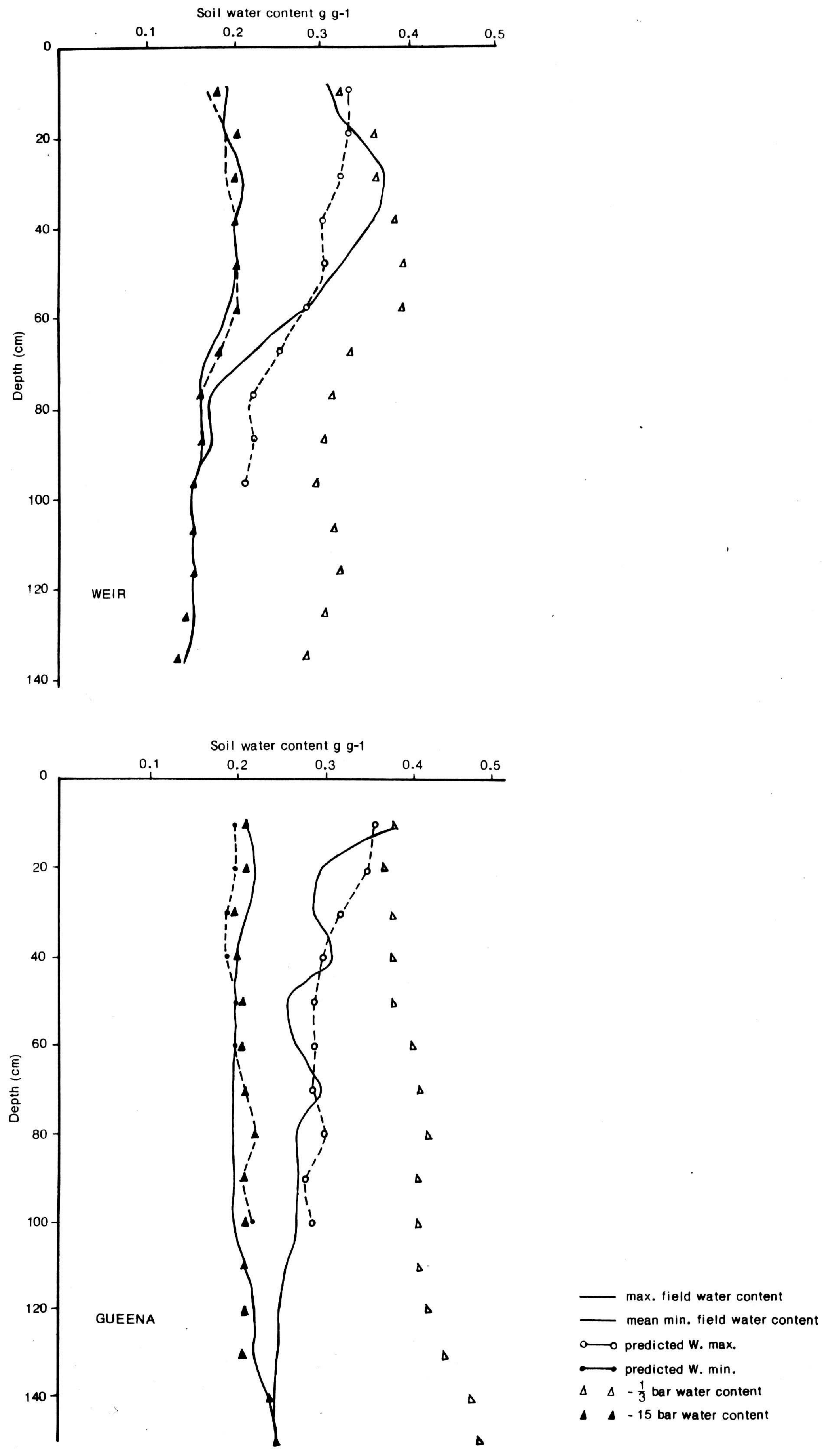


Figure 7 Measured and predicted soil water contents for Weir and Gueena soils.

The predicted W_{max} and W_{min} soil water contents are good estimates of the field values apart from some underestimation for Weir in the 30-40 cm depth. Thus the prediction is applicable to the Byee area to allow the upper and lower field water contents to be determined. The $-^1/_3$ bar moisture content is a poor estimate below the surface 20 or 30 cm.

(b) Prediction of Rooting Depth

Shaw and Yule (1978) related the rooting depth to the depth of maximum rate of increase of chloride concentration. On the results of the experiment on Weir and Gueena, this estimate appears too shallow, and the depth to peak in chloride concentration appears a better estimate of rooting depth.

(c) Prediction of Plant Available Water

The measured available water (volumetric) for the 2 sites based on the available water range between the wettest and driest profiles of the sampled profiles, the wet bulk density (Shaw and Yule 1978) and the actual depths of wetting are given in Table 11. These values agree quite well with the predicted Plant Available Water from -15 bar regressions and the depths to peak chloride.

TABLE 11

Measured and predicted Plant Available Water

Soil	Measured Plant Available Water cm	Depth of Wetting cm	Depth to Peak Chloride cm	Predicted Plant Available Water cm
Weir	13.0	70	60	11.2
Gueena	15.6	130	110	14.4

Plant available water for the four major soils was calculated using mean values for -15 bar water content in the regression equations and depth to peak chloride. Depth to peak chloride showed considerable variability within some soil profile classes but the mean values are considered to be a realistic estimate for the respective profile classes.

Table 12 lists the average depth to peak chloride, the standard error and the Plant Available Water for the major soil profile classes. The few sites in Gueena where there was no peak in chloride have not been included.

The depth of active rooting represents the greatest depth at which water changes are significant between successive irrigations. For shallow rooted crops, the active root zone will be less but for the purpose of this assessment, the depth gives a realistic comparison of the potential available water in the soil.

TABLE 12

Predicted Plant Available Water (PAW) for the 4 major soil profile classes

Soil Profile Class	Av. Depth Cl Peak cm	SE	Modal Depth cm	No. of Profiles	Predicted PAW cm	Relative Rating (Gueena = 100%) %
Weir	90	±8.6	60	9	13.7	91
Byee	100	±8.4	110	6	15.0	99
Eastgate	70	±4.0	60	12	11.5	76
Gueena	100	±3.8	100	7	15.1	100

Gueena and Byee hold most water whilst Eastgate holds least. Soils with high Plant Available Water are easiest to manage and have greater management flexibility (other factors being equal) since they require less frequent irrigations with the associated reduced costs and greater efficiencies of overall water use.

The most efficient management to utilize the amount of Plant Available Water in the soil requires fast water application to allow water entry before the soil cracks close. Flooding is the preferred irrigation method on cracking clays utilizing the network of soil cracking to wet the soil to the rooting depth.

On cracking clays in Emerald, Shaw and Yule (1978) found that 74% of the water entry in 5 hours ponding occurred within 30 minutes of water application. However, if irrigation followed a 30 mm rainfall, only 60% of the water required to replenish the soil water used could enter the soil. Therefore delaying irrigation until the cracks have reopened will allow greater water entry.

7. SOIL RESPONSE TO IRRIGATION

7.1 Soil Changes Under Existing Irrigation

7.1.1 Introduction

Irrigation has been practiced in the area both from the creek and from bores for periods up to 50 years in some cases, with waters of varying quality. Areas which have been consistently irrigated over a period of time should indicate likely salt balance changes in the soil. Any major changes should be evident irrespective of the irrigation management used.

Soil sampling and analysis of paired sites of irrigated and non irrigated areas on the major soils was carried out to indicate potential water quality and soil problems.

In laboratory experiments, by choosing a range of water qualities on the major soil profile classes, acceptable water qualities can be identified which will not cause long term salinity buildup in the soils.

7.1.2 Methods

Farmers were contacted who had irrigated consistently for at least 10 years with either creek water or bore water. Paired sites were chosen in the irrigated area and an adjacent non irrigated area. A total of 5 paired sites were sampled covering 3 of the 4 major soils namely Byee, Gueena and Weir, Table 13. Difficulties in locating a consistently irrigated site on Eastgate prevented its inclusion. For soils Gueena and Weir, both creek and bore irrigated sites were obtained whilst Byee was bore irrigated.

TABLE 13

Site information, soil profile class, source and period of irrigation and major crops grown

Soil Profile Class	Site No.	Location on Soils Map A.M.G. Zone S.G. 56		Source of Irrigation	Period of Consistent Irrigation	Main Crops Grown Recently
Weir	1	384800E	7102000N	bore	10 years	rock melons - other horticulture crops, intensively irrigated in season
Weir	2	384600E	7101700N	creek	10	corn, some soyabeans
Byee	3	380400E	7101600N	bore	5* 40	sorghum, previously lucerne, sorghum, onions
Gueena	4	379500E	7107600N	bore	7**	sorghum mainly
Gueena†	5	377500E	7105400N	creek	14	soyabeans, sorghum

* present owner 5 years, previous owners over 40 years intensive irrigation

** present owner only

† one profile at this site is from the soil profile class Wheatlands

At each paired site 6 profiles were sampled to 150 cm, 3 in the irrigated area and 3 in the non irrigated area. Where possible profiles were taken at 20-30 metre spacings. Each profile was cut into 10 cm increments, dried at 40°C and ground to less than 2 mm after subsampling a few small aggregates.

Electrical conductivity, pH and chloride determinations were made on 1:5 soil water suspensions for every second depth increment - the techniques are reported in Appendix 3. Soil dispersibility of the unground aggregates in deionized water at 2 and 20 hours was estimated by Emerson's dispersion test (Emerson 1967) and reported as Dispersion Index after Loveday (1974)

Bore water samples were taken at the time of soil sampling from those sites bore irrigated and analysed by the standard water analysis methods of Agricultural Chemistry Branch. Previous bore water analyses were obtained where possible with the co-operation of Queensland Water Resources Commission (QWRC). The water analyses are presented in Table 14.

TABLE 14

Water analyses of irrigation bore waters and Barambah and Barker Creek waters

Soil and Site No.	Source of Irrigation Water	Date of Sampling	E.C. µS cm^{-1}	TSS mg l^{-1} (1)	Ca^{++}	Mg^{++}	Na^{+}	HCO_3^{-}	$CO_3^{=}$	$SO_4^{=}$	Cl^{-}	SAR (2)	pHc* (3)	Adj SAR (4)
					Water Analysis (meq/L)									
Weir 1	bore	23.1.79	1350	714	4.7	4.8	2.7	2.6	N.D.*	trace	9.6	1.2	7.15	2.7
		29.1.75	650	318	1.8	1.7	2.2	1.9	-	N.D.	3.8	1.6	7.65	2.8
Weir 2	creek	see creek water data below												
Byee 3	bore	25.1.79	1850	1273	3.0	7.5	9.3	8.1	N.D.	trace	11.7	4.1	6.74	10.9
		6.12.67	1980	1103	3.0	7.7	10.6	9.1	N.D.	0.2	12.0	4.6	6.68	12.5
		1965	2100	1150	4.2	8.3	10.0	8.7	N.D.	0.5	13.2	4.0	6.63	11.1
Gueena 4	bore	25.1.79	2600	1781	5.4	7.4	15.7	8.3	N.D.	trace	20.3	6.2	6.66	17.0
		7-1960	3000+	2045	5.4	8.2	18.8	9.2	N.D.	1.9	21.3	7.2	6.62	20.0
Gueena 5	creek	see creek water data below												
Silverleaf Weir Barambah Creek		26.1.79	700	435	1.8	2.2	3.0	2.2	N.D.	-	4.8	2.1	7.60	3.8
Barker Creek at Wyalla 1962-1977														
best quality		20.10.65	338	179	1.3	0.9	1.2	1.0	-	0.1	2.3	1.2	8.15	1.5
worst quality		8.10.71	2550	1317	5.6	9.4	9.9	3.3	-	trace	21.6	3.6	6.98	8.7

(1) TSS = total soluble salts, Σ analyzed ions

(2) SAR = sodium adsorption ratio = $\frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{\frac{1}{2}}}$ (concentrations in meq/L)

(3) pHc* indicates the tendency to precipitate $CaCO_3$ from the water, <8.4, or to dissolve $CaCO_3$ from the soil >8.4 (Ayers 1977)

(4) adj SAR accounts for the effect of precipitation of $CO_3^{=}$ and HCO_3^{-} on the SAR

adj SAR = SAR (1 + 8.4 - pHc*), (Ayers 1977)

* N.D. - not detected

\+ for this water EC estimated from TSS

7.1.3 Results and Discussion

Figure 8 shows the mean EC and chloride profiles with depth for both the irrigated and non irrigated profiles at the 5 sites. The Weir soil under bore irrigation was the only soil to show a decrease in salinity with irrigation. The remaining 4 sites showed an increase, the least being Weir under creek irrigation. Weir is the lightest textured soil (Appendix 1) and thus probably has greater ease of leaching. The bore irrigated site also has the best quality bore water. The Weir site, bore irrigated, did show a slight increase in soil dispersibility below 40 cm probably reflecting leaching of the salts. The increase is small and probably of limited significance in the field situation.

The increase in salinity in Byee soil was at a depth approximating the normal rooting depth and in this soil, probably reflects the equilibrium profile over many years of irrigation with a moderately high salinity water. Since the increase is at depth, soil permeability can be assumed to be adequate and management satisfactory. The increase in soil salinity would be expected with the particular quality of water being used.

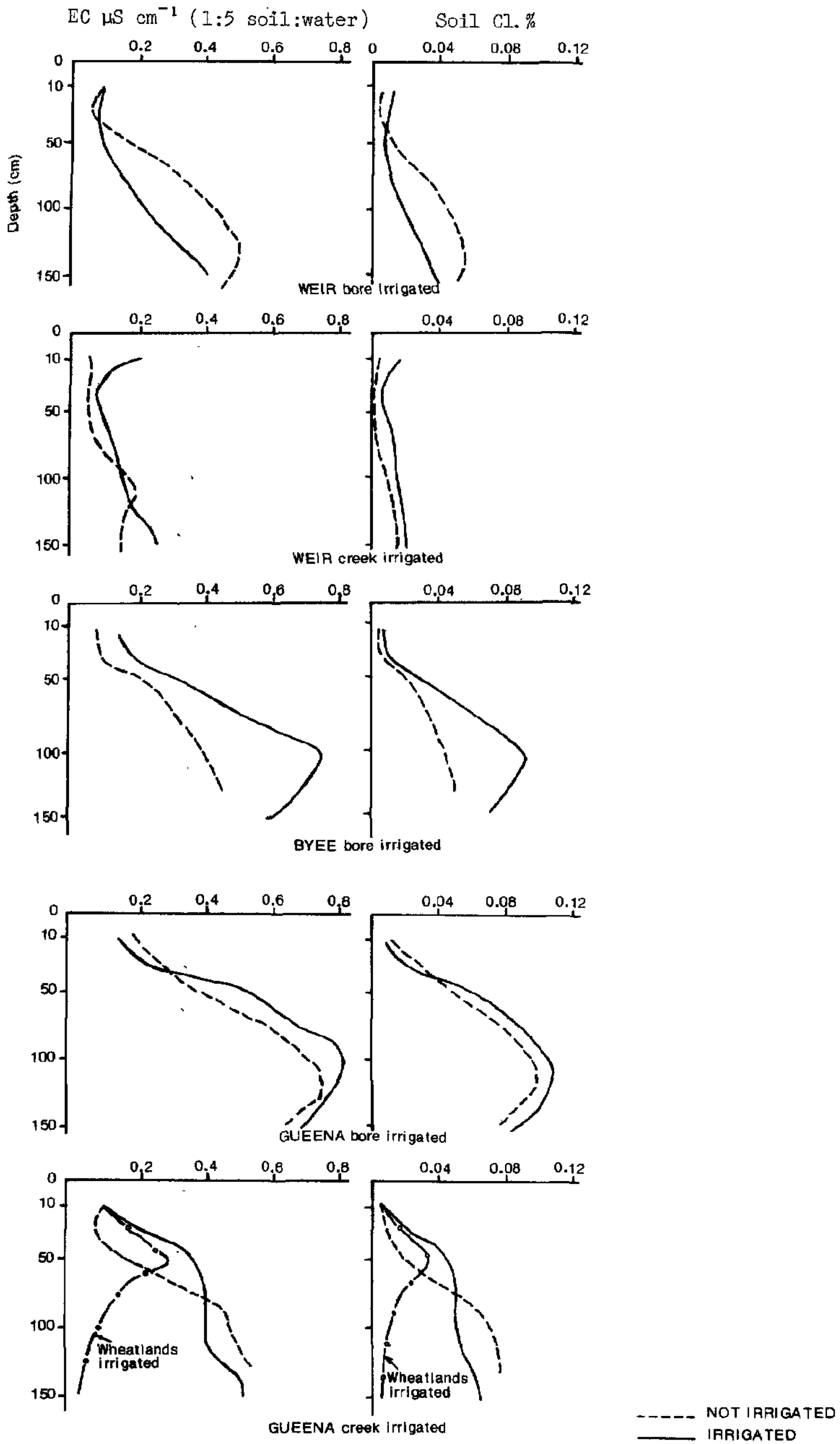


Figure 8 Electrical conductivity and chloride profiles of irrigated and non irrigated sites on three soils.

Gueena soils also show increased salinity. The increase is in the upper root zone (0 - 60 cm) of the creek irrigated site suggesting restricted leaching due either to low soil permeability or management approaches. The slight reduction in salinity below 80 cm suggests some leaching does occur. The bore irrigated Gueena site shows the highest level of salinity. Difficulty was experienced in obtaining a good non irrigated area. High salinity is present even though this site is the least consistently irrigated and had not been irrigated over the previous 9 months.

There was no increase in soil dispersibility at any site other than Weir bore irrigated.

The increased salinity in the heavier soils, Byee and Gueena, suggests a water with lower salinity than those used for these soils would be desirable for long term stable irrigation under a range of conditions. Byee is considered a well structured permeable soil compared to the more sodic Eastgate soils and the Gueena soils. These latter two soils are considered most at risk from waters of high salinity. Based on this study of the effects of present irrigation practice on accumulation of salt in the root zone the maximum salinity of irrigation water should be appreciably less than EC 1900 µS cm^{-1} (Byee bore).

7.2 Effect of Irrigation Water Quality on Surface Soil Behaviour

7.2.1 Introduction

The quality of the water in Barambah Creek is variable depending on the seasons. The poorer quality water during dry times is unsuitable for stable long term irrigation. Some of this information is provided in section 7.1. However, the surface soil behaviour is also of importance, particularly any physical deterioration which may affect establishment and infiltration. The proposed water storage on Barker Creek will receive cooling water blowdown from Tarong Powerhouse, which may also affect water quality but can be controlled. The safe acceptable water quality for long term irrigation is influenced by factors including crop, soil type and climate. Two factors of water quality which require clarification are acceptable levels of overall salinity both in terms of the soil and the plant and acceptable levels for water sodicity to prevent adverse soil problems such as dispersion resulting in reduced water entry.

An investigation was made to determine the effect of a range of expected water qualities on the surface soil infiltration under irrigation, and infiltration when the irrigation is followed by rain.

7.2.2 Soils, Waters and Methods

Soils

The 0-10 and 10-20 cm depths of the 4 major soils of the Byee Area viz, Weir, Byee, Gueena and Eastgate were sampled, dried at 40°C, and ground to <2 mm. The 1 - 0.5 mm size fraction was separated and packed into 8.2 cm diameter perspex columns. Packing was carried out by placing a 7 cm diameter open ended tube inside the column on top of a layer of 2 - 1 mm sand and gauze. Three hundred and fifty grams of the 10 - 20 cm depth was added followed by 350 g of the 0 - 10 cm depth. The inner tube was lifted slowly as the column was rotated and tapped. Finally the column was dropped 10 times from a height of 4 cm. The height of soil in the column and the air dry moisture content of a sample of the sieved soil were determined.

Waters

Records of water quality in Barker Creek at the Wyalla station, (Queensland Water Resources Commission unpublished data) were examined to determine the range and trend in water quality over the period 1962 - 1977. This is the nearest water quality data available for Barambah Creek. The waters range in electrical conductivity from 350 to 2550 µS cm^{-1} with corresponding sodium adsorption ratios (SAR) of 1.3 to 3.7. There is a consistent trend between SAR of the waters and the electrical conductivity throughout the range and over the years. (Figure 9).

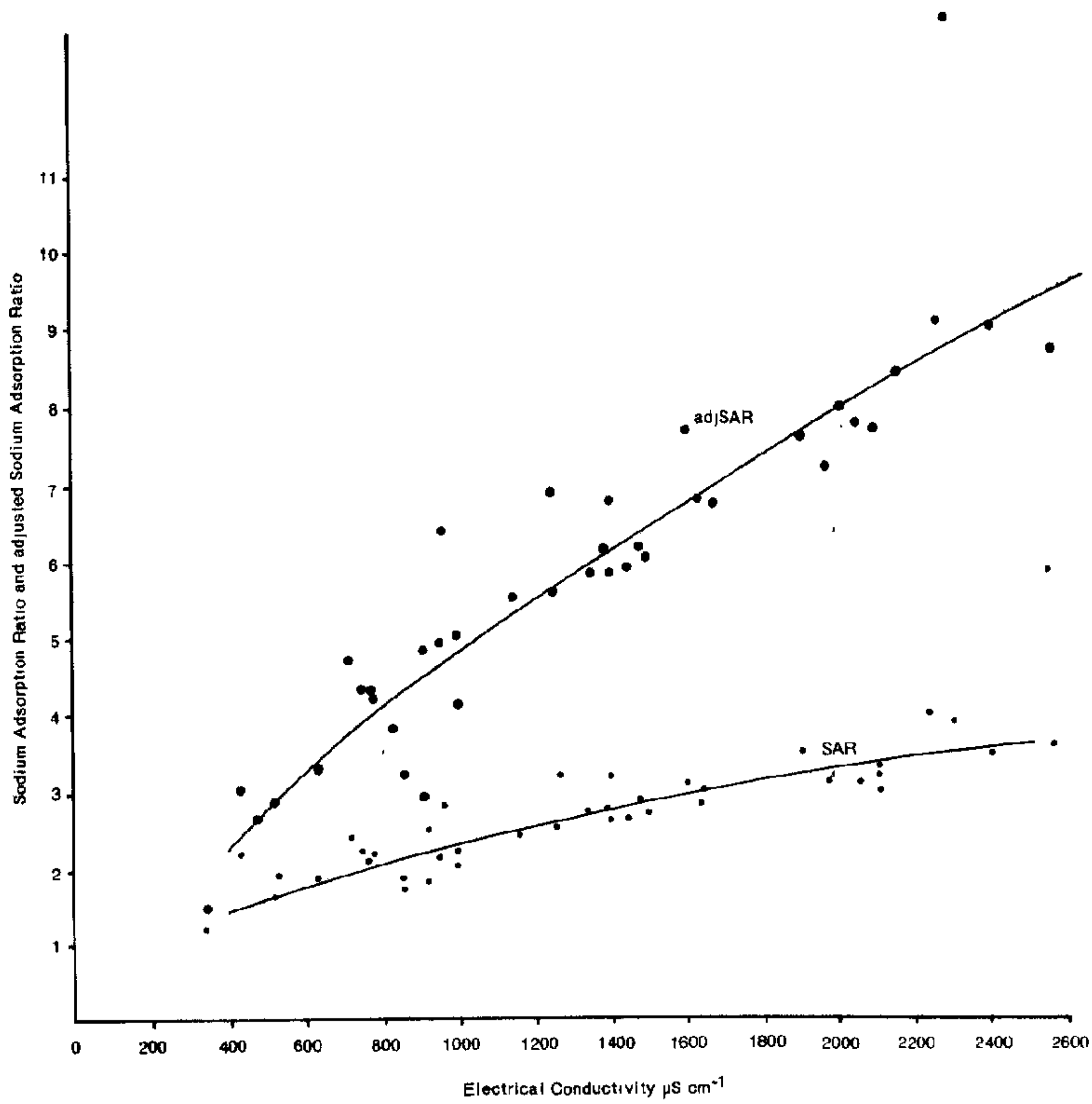


Figure 9 The relationship between sodium adsorption ratio, adjusted sodium adsorption ratio and electrical conductivity of Barker Creek water at Wyalla.

On the basis of the range in quality, 4 water qualities were chosen to represent the range including the water in Silverleaf Weir at the time of soil and water sampling (January 1979). To approximate the possible quality of the cooling water blowdown from Tarong Powerhouse, a fifth water equivalent to the approximate average blowdown water from Swanbank Powerhouse (D. Ryan personal communication) was included. The waters were made up to the required concentrations by adding calculated quantities of the required salts (AR grade) to the water from Silverleaf Weir. Table 15 gives the water qualities used and the ionic composition.

Rain water from the storage tanks at the Indooroopilly laboratories was also used. The analysis of this water is given in Table 15. Phenol was added to all waters to inhibit microbial growth with a final concentration of 0.1% Phenol.

TABLE 15

Irrigation water qualities

Analysis	Irrigation Water					Rain Water
	A	B	C	D	E	
Electrical Conductivity $\mu S\ cm^{-1}$	680	1030	1700	2250	2500	70
Ca^{++} m.equiv. L^{-1}	1.9	2.1	4.1	5.4	19.8	0.4
Mg^{++} "	2.3	4.7	7.0	10.1	1.1	N.D.
Na^{+} "	2.7	3.4	6.1	8.6	11.8	0.5
HCO_3^{-} "	2.4	3.0	2.5	3.3	2.6	0.5
Cl^{-} "	4.5	7.2	14.7	20.8	14.1	0.4
$SO_4^{=}$	-	-	-	-	14.0	-
SAR	1.9	1.8	2.6	3.1	3.7	1.12
pHc*	7.58	7.19	7.19	6.89	6.98	9.14
adjusted SAR†	3.5	3.9	5.8	7.5	8.8	-

* pHc* indicates the tendency to precipitate $CaCO_3$ from the water, <8.4, or to dissolve $CaCO_3$ from the soil >8.4 (Ayers 1977)

† adjusted SAR accounts for the precipitation of $CO_3^{=}$ and HCO_3^{-} on the SAR, adj. SAR = SAR (1 + 8.4 - pHc). (Ayers 1977)

Methods

The experimental design involved 4 soils each ponded with 5 different water qualities. Subsequently each was ponded with rain water.

All soils were ponded under a head of approximately 1 cm of the appropriate irrigation water for between 16 and 24 hours until approximately 5 pore volumes had passed through the soils. Depth of wetting, swelling and rate of outflow were measured regularly. After the required amount of irrigation water had passed through the soils, the soils were allowed to drain for at least 2 hours and then ponded with rain water until at least 5 pore volumes had passed through the soil. The electrical conductivity of the outflow under rain water was measured periodically.

Waters were analysed by the standard water analysis methods of Agricultural Chemistry Branch.

7.2.3 Results and Discussion

Table 16 shows the bulk density of the packed soil column, the pore volume of the soil in the swollen state, the degree of soil swelling and the water content of the cores on completion after draining for 1 day. One pore volume is equal to the amount of water required to fill the soil pore space when the soil is in the swollen condition. The packing had acceptable uniformity within soils. The degree of swelling is greatest for Byee as expected from the clay activity ratio and clay content and least for Weir with lower clay content. (Section 5).

TABLE 16

Mean bulk density, pore volume, degree of swelling and soil water content after draining for the 5 columns of each soil

Soil	Dry Bulk Density		Pore Volume of Wet Soil		Degree of Vertical Soil Swelling		Water Content after 1 day Drainage		% Saturation after 1 day Drainage	
	$g\ cm^{-3}$	S.E.	cm^{-3}	S.E.	%	S.E.	$g\ g^{-1}$	S.E.	$g\ g^{-1}$	S.E.
Byee	0.99	±0.006	570	±2.40	29.6	±0.25	0.80	±0.002	0.89	±0.002
Gueena	1.04	±0.004	483	±3.78	18.2	±0.58	0.65	±0.002	0.88	±0.006
Weir	0.98	±0.004	484	±4.99	8.2	±0.37	0.60	±0.003	0.81	±0.004
Eastgate	0.97	±0.008	521	±3.78	13.8	±0.58	0.69	±0.002	0.86	±0.008

Table 17 summarises the outflow results listing the rates at specified times for the irrigation and rain waters, and the number of pore volumes passing through the soil.

TABLE 17

Outflow rates at specified times for both irrigation waters and rain water for 5 soils

Soil and Irrigation Water*	Outflow Rate after 5 Hours with Irrigation Water $cm\ hr^{-1}$	Pore Volumes at 5 Hours	Total Pore Volumes of Irrigation Water	Outflow Rate after 6.5 Hours with Rain Water $cm\ hr^{-1}$	Pore Volumes at 6.5 Hours	Outflow Rate after 22 Hours with Rain Water $cm\ hr^{-1}$	Pore Volumes after 22 Hours
Byee A	3.18	1.5	5.0	3.66	2.0	2.98	6.6
B	3.07	1.5	4.7	2.95	1.6	1.98	5.8
C	3.51	1.6	4.8	2.99	1.8	1.70	5.7
D	3.59	1.6	4.7	3.31	1.7	1.80	6.0
E	2.73	1.2	4.7	2.45	1.4	1.46	4.7
Gueena A	3.37	1.4	6.5	3.45	2.1	2.34	7.6
B	3.51	1.4	6.4	3.62	2.3	2.14	7.7
C	3.63	1.5	6.5	3.47	2.4	1.75	7.3
D	3.74	1.5	6.7	3.40	2.4	1.80	7.4
E	3.59	1.3	6.3	3.01	2.0	1.69	6.3
Weir A	5.33	2.8	7.7	5.70	4.1	-	8.8
B	6.21	3.3	7.7	5.91	4.4	-	8.8
C	7.00	4.1	7.7	5.37	4.2	-	8.7
D	6.60	3.8	8.0	5.04	4.1	-	9.2
E	7.07	4.1	8.2	5.86	4.5	-	9.1
Eastgate A	2.65	1.4	7.3	2.66	1.6	1.80	5.7
B	3.52	1.7	7.3	3.59	2.2	2.64	8.2
C	4.69	2.2	6.8	4.17	2.8	-	7.9
D	4.63	2.1	7.0	3.86	2.8	1.95	7.5
E	4.96	2.2	7.1	4.87	3.2	-	6.3

* Irrigation water indicated by letter, see Table 15

(i) Irrigation Waters

The general trend is for the saturated hydraulic conductivity (rate of outflow) to increase as the salinity of the irrigation water increases. Table 18 gives the relative rates for each soil at 5 hours. The lowest increase occurs in Byee and Gueena soils and the highest in Eastgate. Both Byee and Gueena have low exchangeable sodium percentages (ESP) whereas Eastgate has high ESP in the surface (Appendix 1). Here the increasing salinity results in flocculation of the soil with consequent increased rate of outflow. The biggest increase in rate of outflow occurs with waters C, D and E indicating waters with E.C. above 1000 µS cm^{-1} have greater effect on flocculation. The reason for the low rate for water E on Byee is unknown.

For Weir and Eastgate soils where 8 hour rates are also available, the rate for Weir has remained essentially constant whilst for Eastgate, the rate has continued to increase substantially. This is probably a direct effect of the smaller quantity of water which has passed through Eastgate after 5 hours and thus a continuing reaction with the soil.

TABLE 18

Relative rates of outflow for the 4 soils at 5 hours with 5 irrigation waters

Soil	Relative Rate of Outflow Irrigation Water A for each soil = 100%				
	Irrigation Water				
	A	B	C	D	E
Byee	100	97	110	113	86
Gueena	100	104	108	111	107
Weir	100	117	131	124	133
Eastgate	100	133	177	175	187
Mean	100	113	132	131	128

(ii) Rain Water

By leaching the soil with rain water after the respective irrigation waters, any deleterious or beneficial effects of the irrigation waters on the soils can be evaluated.

The rates of outflow after 6.5 and 22 hours of leaching with rain water are presented in Table 17. The relative rates of outflow at each of the two times are shown in Table 19.

For Byee soil, there is a decrease in outflow rate for rain water after irrigation waters higher in salinity than water A, 700 µS cm^{-1}. The outflow rate for A decreased only 19% between 6.5 and 22 hours. For Gueena soil the outflow rates at 6.5 hr are about equal except for water E, with a reduction particularly in columns with waters C, D and E by 22 hours. The reduction in outflow rate for column A is 32% in this soil, considerably less than for the other columns.

TABLE 19

Relative rates of outflow with rain water at 6.5 and 22 hours

Soil	Time of Outflow (hours)	Relative Rates of Leaching with Rain Water (cm/hr) (soils irrigated with water A = 100%)				
		Irrigation Water				
		A	B	C	D	E
Byee	6.5	100	81	82	90	67
	22	100	66	57	60	49
Gueena	6.5	100	105	101	99	87
	22	100	91	75	77	72
Weir	6.5	100	104	94	88	103
	22	-	-	-	-	-
Eastgate	6.5	100	135	157	145	183
	22	100	147	-	108	-

For Weir the 22 hour rate could not be obtained because of the high hydraulic conductivity of this soil. However at 6.5 hours, there was no significant reduction in rate. Eastgate is the only soil which maintained rates substantially above the rate through column A both at 6.5 hours and 22 hours for the rates available.

The reverse mechanism to irrigation with saline water occurs for rain water. As the salinity is reduced through leaching, the effect of exchangeable sodium increases causing soil dispersion and reduced flow. For Byee and Gueena soils, the ESP after irrigation with waters C, D and E will probably be higher than in the original soil resulting in reduced rates. For Weir and particularly for Eastgate the ESP will be lower and hence higher outflow rates will be maintained. (The ESP of the soil in equilibrium with the irrigation water can be estimated by SAR, U.S. Salinity Laboratory Staff 1954).

The results indicate that irrigation with waters C, D or E will reduce outflow in Byee and Gueena. Water B will also cause a reduction for Byee.

Table 15 indicates that the pHc for rain water is 9.14 which indicates a strong tendency to dissolve calcium carbonate in the soil (Bower, Ogata and Tucker 1968). This may be affecting the exchangeable cation equilibrium and will have significant effects for Byee with higher montmorillonite clay.

The relationship derived by Quirk (1971) to express the electrolyte concentration required to maintain stable permability with a given SAR value, viz

$$\text{electrolyte concentration} = 0.56\,(\text{SAR}) + 0.6$$

(all concentration expressed as m.equiv/litre)

indicates that the rain water used will not maintain stable permeability for SAR values of greater than about 0.5. This means the irrigation waters in this experiment in the long term will give SAR values greater than 0.5 and hence some dispersion will occur under rainfall, being most pronounced with irrigation waters of higher SAR values.

(iii) Salt Leaching

Figure 10 shows the break through curves after leaching the columns irrigated with water E. The amount of water required to drop the salt concentration to 10% of its initial value is least for Weir, approx. 0.9 pore volumes, followed by Byee and Gueena with approx. 1.5 pore volumes and then Eastgate requiring 1.8 pore volumes. This indicates the greater difficulty in removing salts from the heavier soils. This will be a considerable problem for Eastgate soil with high sodicity throughout the profile.

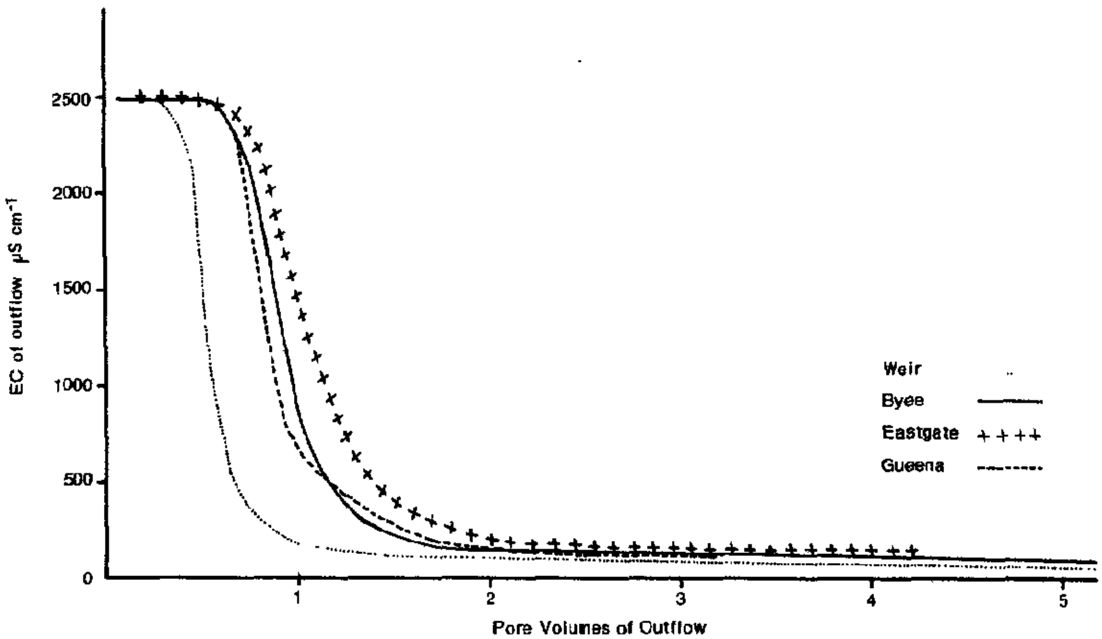


Figure 10 The electrical conductivity of the outflow of columns irrigated with water E when leached with rainwater.

7.2.4 Conclusions

Irrigation with waters having qualities worse than irrigation water B viz EC 1000 μS cm^{-1} and SAR 2 will result in reduced infiltration rates for the heavier soils Byee and Gueena under rainfall. More saline waters will have less effect on the lighter textured Weir and assist considerably in flocculating the sodic Eastgate soils, but with an associated increase in soil salinity.

Leaching of salts will require more water for the heavier clay soils, Eastgate, Byee and Gueena than Weir.

7.2.5 Application to Field Conditions

Water entry in the field under irrigation is through cracks open to the soil surface so that under normal conditions, the increase in infiltration rate indicated here for irrigation water will not be significant.

However if an irrigation is followed by rainfall, or if the soils are subject to prolonged rainfall or to flooding soil physical problems in the surface will result. The most pronounced effect being soil dispersion, and slaking resulting in surface crusting, cloddiness after cultivation and poor water entry.

The soils in this experiment were not subject to wetting and drying cycles as in the field situation. Wetting and drying cycles will result in concentration of salts and precipitation of the less soluble salts as calcium and magnesium carbonates. Calcium sulphate will also be precipitated for water E. This precipitation has a net effect of increasing the SAR. The adjusted SAR of Table 15 indicates the likely SAR after precipitation of carbonates. Thus in the field situation the salinity and sodicity are both increased by wetting and drying. Irrigation water C has an adjusted SAR of 6 which on the water quality criteria of Ayers (1977) is the upper limit above which soil permeability problems may occur in soils high in montmorillonite. McIntyre (1979) has also suggested an ESP of about 5 for clay soils above which physical properties are affected. The problem of maintaining an acceptable salt level for plant growth through adequate leaching is discussed in section 7.3.

Based on these laboratory experiments a water quality in which the EC does not exceed 1000 $\mu S\ cm^{-1}$ and the adjusted SAR does not exceed 6 appears to be acceptable for stable long term irrigation of soils in the Byee area. Irrigation with water of EC up to 1500 $\mu S\ cm^{-1}$ is considered acceptable for limited periods. In the short term such waters would cause deleterious effects only in the more salt sensitive crops. However long term use of waters with EC appreciably in excess of 1000 $\mu S\ cm^{-1}$ could lead to a buildup of undesirable levels of soil salinity.

7.3 Irrigation Water Quality and Plant Tolerance to Salinity and Sodicity

7.3.1 Introduction

Irrigation water affects plant growth directly through the quantity and composition of the salts in the water and indirectly through the effect of the salts on soil properties. Evapotranspiration increases the concentration of the salts in the soil to a high level if adequate leaching is not attained. Thus there is a balance between the quality of the irrigation water, the tolerance of plants to salinity and the amount of leaching required.

The literature contains many references to the tolerances of plants to salinity and sodicity and whilst precise levels require an understanding of the soil, climate, and management processes, the data is useful in planning irrigation to achieve acceptable water qualities and leaching of salts.

Using the published salt tolerances and the range of irrigation water qualities discussed in section 7.2, an assessment is made of irrigation water quality in terms of the tolerance for the crops grown in the area and the degree of leaching required to maintain satisfactory levels of soil salinity and sodicity.

7.3.2 Crop Tolerance

(a) Salinity

The main crops grown and likely to be grown in the area are a soybean - barley rotation with wheat and oats as minor substitutes for the winter rotation and sorghum, sunflower and maize as substitute in the summer rotation. Limited areas of lucerne, potatoes, pumpkins, onions and navy beans will also be grown.

Ayers (1977) presents extensive crop tolerance levels for both soil and water salinities for various levels of yield decline. Leaching requirements to prevent excessive salt concentration are also given. Table 20 lists the tolerances for 0% and 10% yield decline taken from the data of Ayers (1977) for the crops grown in the area.

If the crops maize, beans, potatoes, onions and lucerne are to be grown, the highest salinity in the irrigation water allowable is in the order of 1000 $\mu S\ cm^{-1}$. This may give a slight reduction for beans and onions.

(b) Sodicity

The maximum likely sodicity of the irrigation waters based on the available data - Table 15,is adj SAR = 9, which will result in a maximum exchangeable sodium percentage of about 11 using the relationship given by U.S. Salinity Laboratory Staff (1954). Beans are the only crop likely to be affected at this level since they are sensitive to sodium at an ESP level of 10 - 20 (Pearson 1960). If the level recommended in section 7.2 is adopted none of the crops listed should be affected by sodium.

7.3.3 Salt Leaching

Table 20 indicates that leaching requirement for the sensitive crops is about 4 to 8% if an irrigation water of salinity about 1.0 $mS\ cm^{-1}$ is used. This should be attainable in the long term for most soils. Eastgate may be more of a problem because of the very high ESP throughout the profile giving restricted internal drainage. Gueena soils may also be a problem, the data of section 7.1 indicate some build up of salts in the root zone of this soil. Some importance should be placed on irrigation management for the heavier soils to ensure only limited salt build up occurs. To attain adequate leaching, pre and post cropping irrigation may be required to provide sufficient water at the bottom of the root zone for some movement to occur. If the soils are dry at depth, little water will probably pass below the root zone since it will be used by the crop, but if the soil is fully wet, the initial irrigations at least will allow water to move below the root zone. A post cropping irrigation will assist in leaching salts as water will be present in the root zone for a considerably longer time than under a crop.

Summer rainfall together with periodic flooding will also assist in maintaining an adequate salt balance. In areas where there are saline soils (see section 5.3) this salt will move into the water table. Adequate control of the water table level is of utmost importance to prevent soil salinization.

TABLE 20

Crop tolerance to salinity

Crop	Expected Yield Reduction					
	0%			10%		
	EC_{SE}[1]	EC_W[2]	LR[3]	EC_{SE}	EC_W	LR
Barley	8.0	5.3	10	10	6.7	12
Sunflower*	7.0	4.7	10	8.7	5.8	12
Wheat	6.0	4.0	10	7.4	4.9	12
Soybeans	5.0	3.3	17	5.5	3.7	18
Sorghum	4.0	2.7	7	5.1	3.4	9
Peanuts	3.2	2.1	16	3.5	2.4	18
Maize	1.7	1.1	6	2.5	1.7	8
Beans	1.0	0.7	5	1.5	1.0	8
Potatoes	1.7	1.1	6	2.5	1.7	8
Onions	1.2	0.8	5	1.8	1.2	8
Lucerne	2.0	1.3	4	3.4	2.2	7

* extrapolated from data by FAO 1973

Specific data for oats and pumpkins is not available

1 EC_{SE} = electrical conductivity of the soil saturation extract in mS cm^{-1}.

2 EC_W = electrical conductivity of the irrigation water, mS cm^{-1} assuming the salinity of the irrigation water increases about 3 times in the soil (Ayers 1977). In terms of the EC_{SE}, the $EC_W = {}^2/_3\ EC_{SE}$.

3 LR = the minimum leaching fraction to control soil salinity to within the tolerance level given expressed as % of irrigation water applied.

8. LAND USE

8.1 Present Land Use

An estimated 4400 ha or 80% of the net area unoccupied by infrastructure (roads etc.) in the study area is under cultivation. The remaining area is used for grazing of native pastures or is occupied by drainage lines, gullies or creeks. Irrigation is practised on 600 ha (Queensland Water Resources Commission unpublished data) or 14% of the cultivated area. An estimated 30% of the cultivated area is double cropped in any one year.

The principal crops in the area are barley, sorghum, soybeans, wheat and sunflowers. Minor areas are sown to forage sorghum, lucerne and oats for grazing. Rainfall variability is high and crop yields frequently suffer the effects of moisture stress. Waterlogging and flood damage also reduce yields on some occasions.

Irrigation practices are generally aimed at supplementing water availability to the above crops rather than supplying them with sufficient water to obtain maximum economic yields. Intensive irrigation is not widely practised because water supply from the creek is not assured and because its quality is variable.

Approximately 45 ha of small crops are grown in the area under intensive irrigation (Queensland Water Resources Commission unpublished data). The most common crops are onions, potatoes and the cucurbits. Minor areas of peanuts are also irrigated.

8.2 Likely Changes Under Irrigation

It is likely that the provision of adequate irrigation water supplies of acceptable quality would have the following effects on land use patterns in the area.

- Increase the yields of crops presently grown under dryland and supplementary irrigation conditions.
- Increase the cultivated area by inducing cultivation on some of the areas presently used for grazing.
- Increase the proportion of the cultivated area that is double cropped to an estimated 60 to 70% of that cultivated.
- Allow the introduction of new crops and expansion of the area under small crops.
- Reduce the year to year variability in crop yields.

The suitability of the area for irrigation is dependent on climate, soils, topography, drainage and crop management.

8.3 Physical Limitations to Irrigation

8.3.1 Drainage

As mentioned in section 2.5.1 surface drainage from much of the area is extremely slow. To allow large scale irrigation development of the area it will be necessary to construct an integrated drainage scheme to collect irrigation runoff water, rainfall runoff and flood runoff. This scheme should be designed to collect water from the lowest point or points on all farms and channel it back to the creek. It may be feasible to construct ditches to speed the flow of water along existing drainage lines or it may be necessary to construct more openings in the creek levee. Because the area is subject to extensive flooding and because drainage works will occupy low landscape positions, they should be designed to be submerged by flood waters and then to remove surface water rapidly as levels subside.

The Byee, Eastgate and Gueena soils will need particularly careful drainage because of their generally low slopes and their landscape positions. Drainage necessary to remove excess water from the other soils to an integrated drainage scheme should be easily accomplished by landholders.

8.3.2 Flooding

Section 2.5.1 indicates that flooding is a common occurrence in the area at present. It has been estimated that, after a significant water storage has been constructed on Barker's Creek, flood frequency will still be approximately once every two years (Queensland Water Resources Commission unpublished data). Flooding is most likely in the October to March period when winter crops are mature or harvested and not likely to suffer significant losses. Summer crops are susceptible to damage but soybeans, an important summer crop in the area, is resistant to flooding. Wherever possible, irrigation infrastructure should be designed to withstand submergence or, for semi-portable equipment such as pumps, to be raised above flood level.

8.3.3 Limits to Flood Irrigation

Parts of the area studied are considered to be unsuitable for flood irrigation because of high slopes or short slope lengths. An estimate of the proportion of the area in this category was made from records of slope taken during the soil survey and from a further inspection of the area. Land with slopes greater than 1.5 to 2% and/or possible irrigation run lengths of less than 100 to 150 m was classed as unsuitable. It is estimated that 2000 ha or 33% of the gross area surveyed is not suited for flood irrigation. None of the minor mapping units are considered suitable for flood irrigation and the estimated gross areas of the major mapping units considered suitable are as follows: Weir 700 ha (34%) Byee 483 ha (100%) Eastgate 950 ha (81%) and Gueena 1700 ha (88%).

8.3.4 Salinity Hazards

Aside from the accumulation of salt and/or sodium in the soil as a result of the long term use of poor quality irrigation water (see section 7.1) soil salinity problems in the area could occur through two mechanisms:

. A rise in water tables due to the expansion of irrigation and double cropping could bring saline ground waters together with salt accumulations in the soils into the crop root zone. The soil sampling program showed that some sites towards the centre of the area as well as some near the margins had high salt levels in their subsoils and groundwaters in some parts of the area are already saline. As the aquifer systems underlying the area appear to be connected to Barambah Creek (section 2.5.2), ground water will only rise if the maximum rate of water loss from the aquifers to the creek is insufficient to cope with the extra water inputs from deep profile drainage of irrigation water.

. Incursions of saline ground and surface waters from the surrounding hills could cause salinization of a significant proportion of the area. Saline seepages have been observed within 3 km of the surveyed area in the vicinities of Merlwood and Barlil and soil samples taken in the surveyed area near drainage lines from these areas show high levels of salinity to within 50 cm of the soil surface. A profile sampled adjacent to the Mondure beds as mapped by Hill, Tweedale and Skerman (1955) showed high salinity in the subsoil, so saline incursions from this geological formation are also likely to occur. If groundwater levels rise under intensive irrigation this may force incursion of saline waters from adjacent uplands closer to the surface in the surveyed area.

Large scale irrigation development is likely to increase the rate at which water from the aquifers underlying the study area enters the creek. As some of these aquifers are already saline, the salinity of creek waters below the area may be increased appreciably in times of low flow.

8.4 Crop Management

Successful long term irrigation of the area will only be possible if irrigation water is of a quality that does not cause salt or sodium to accumulate in the soil profile and if water tables remain below the crop root zone. The following assumes that these problems do not arise.

From current cropping patterns in the area and discussion with Departmental Extension Officers, it is possible to list crops suitable for growing on the mapped soils using presently available technology. It is also possible to identify potential soil limiting factors and likely management problems from soil morphology and available analytical results. Table 21 sets out likely soil limitations, irrigated crop suitability and management problems for the soils. Land capability classification is given in Appendix 6.

TABLE 21

Soil limitations, irrigated crop suitability and management problems

Soil Profile Class	Soil Limitations		Crop Suitability	Likely Specific Management Problems
	Physical	Chemical		
Wheatlands	Slope Erosion Surface crusting	No major problems Possible zinc deficiency	Navy beans, peanuts, soybeans, sunflowers, barley, wheat, maize, sorghum, fodder crops	Emergence
Tregear	Slope Erosion Waterlogging Impermeable upper B horizon	Medium to high sodicity below 50-90 cm	Barley, wheat, sorghum, oats	Trafficability after rain Emergence
Terrace	Slope Erosion Flooding	No major problems	Pasture only, no crop recommended	Flooding and erosion prevent safe cultivation
Weir	Slope Surface crusting	Variable salinity Low to moderate sodicity below 60 cm	Small crops, potatoes, pumpkins, navy beans, soybeans, sunflowers, barley, wheat, maize, sorghum, fodder crops, lucerne	Emergence The short runs possible make a substantial part of area unsuitable for flood irrigation Flood irrigation should be across the slope in high slope situations
Byee	Temporary waterlogging	Variable phosphorus status Variable salinity	Soybeans, sunflowers, barley, wheat, maize, sorghum, fodder crops, lucerne	Emergence Narrow range of soil moisture content for successful cultivation. Drainage necessary to remove irrigation and rain runoff Row crops should be planted on substantial hills to minimize waterlogging
Eastgate Kaber	Surface crusting Gilgai Temporary waterlogging Variable crop performance Lower plant available water	Medium to high salinity below 40-70 cm Strongly sodic below 30 cm Possible zinc deficiency in Eastgate	Soybeans, barley, wheat, sorghum, fodder crops	Emergence Narrow range of soil moisture content for successful cultivation Drainage necessary to remove irrigation and rain runoff Row crops should be planted on substantial hills to minimize waterlogging
Gueena	Gilgai Temporary waterlogging Flooding	Variable phosphorus status Medium to high salinity below 60-90 cm	Soybeans, barley, wheat, sorghum, fodder crops	Emergence Narrow range of soil moisture content for successful cultivation Flooding may cause some crop failures Drainage necessary to remove irrigation and rain runoff and flood water once run on ceases Row crops should be planted on substantial hills to minimize waterlogging

8.5 Irrigation Management

Flood irrigation will allow efficient water distribution within the soil. High application rates will maximise water entry before the cracks close. Short times may be possible provided adequate leaching of salts can still be maintained.

Irrigation after rainfall will not replenish the water used by the crop as the swollen surface soil will restrict water entry. Therefore irrigation should be delayed until the surface cracks reopen.

Irrigation should be applied when the accumulated evapotranspiration is about 60-70% of the Plant Available Water (PAW) i.e. when 60-70% of the Plant Available Water is used by the crop. Assuming a potential evapotranspiration rate of up to say 0.8 cm/day, this will mean irrigation frequencies of about every 11 - 13 days for Byee and Gueena soils to about every 8 - 10 days for Eastgate soils (based on Table 12) when there is no rainfall. Good lateral wetting will occur, through soil cracks, if the soils are irrigated at 60-70% of Plant Available Water so that wide irrigation furrow spacings are possible.

With poorer quality irrigation water, furrow irrigation will lead to salt build up in the top of the hills. If salt build up does occur, planting into the sides of the hills will reduce the salt effects around the plants, particularly for shallow rooted salt sensitive crops.

Irrigation water with high sodicity will result in sealing and dispersion in the irrigated furrows and crusting and cloddiness problems which will be aggravated under rainfall. Precropping and post cropping irrigations will give greater leaching of salts which accumulate in the root zone through evapotranspiration but will not leach salt accumulations out of the hills.

8.6 Cultural Management

Cultivation should be done at about the optimum soil water content to obtain optimum seed bed conditions and maintain soil structure. The optimum soil water content is when the soil is just moist enough that the clods will break down without smearing or powdering. The optimum water range will be least for Byee and Gueena being the heavier soils, and greatest for Weir. Eastgate will be difficult to manage because of the high sodicity and will also have a narrow range. Use of heavy machinery on wet soils should be avoided as much as possible.

8.7 Sodic Soils

Some areas of Eastgate soils are sodic in the 0-20 cm depth. These soils require careful management to maintain productivity.

Cultivation at the optimum moisture content is important if optimum seedbed conditions are to be achieved. Fine seedbeds will result in greater crusting than medium seedbeds. Protection of the surface soil by organic residues will assist in reducing crusting together with incorporation of organic matter and/or applications of gypsum at rates of 8 - 12 tonnes per hectare. Deep furrows will assist in maintaining optimum structure in the hills under flood irrigation. Sprinkler irrigation will tend to increase crusting due to disruptive forces and should be avoided in the preparation and early establishment periods.

Leaching of salts will be more difficult on sodic soils because of the restricted internal drainage and therefore longer irrigation times may be required. Irrigation when the soil is cracked will allow greatest water entry due to the very low infiltration rate of the wet soil.

Sodic soils require greater management precision and input to obtain optimal production. Under poor management soil deterioration will inevitably occur.

9. GLOSSARY

Mapping Unit: An area or group of areas coherent enough to be represented to scale on a map, which can be adequately described in a simple statement in terms of its main soil profile classes. (Beckett and Webster 1971).

Microrelief: A repeating pattern of surface undulations, usually gilgai.

Plant Available Water (PAW): The volume of soil water, in the active root zone, available to the plants expressed in cm.

Soil Profile Class: A group or class of soil profiles, not necessarily contiguous, grouped on their similarity of morphological characteristics. (Beckett 1971, Beckett and Burrough 1971, Beckett and Webster 1971, Burrough *et al.* 1971). As mapped, they are representative of bodies of soil with similar parent materials, topography, vegetative structure, and generally vegetation composition.

Soil Profile Class - Dominant: The soil profile class that occupies >60% of a mapping unit area.

Soil Profile Class - Associate: The soil profile class that occupies 10 to 20% of the mapping unit areas.

Soil Profile Class - Minor: The soil profile class that occupies <10% of the mapping unit area.

10. ACKNOWLEDGEMENTS

Thanks are due to several people who assisted in some way for the successful completion of this investigation.

Nick Delaney and Peter Vance, Agriculture Branch, Kingaroy for discussions and valued information on crop responses. Frank McKeown, Development Planning Branch, Maryborough for information and suggestions based on his data and interviews. Kep Coughlan and Ron McDonald, Agricultural Chemistry Branch, Brisbane for advice and assistance in interpretation of experimental data and pedology respectively.

Sharon Wallace, Drafting Section, Division of Land Utilisation, Brisbane who compiled the soils map.

John Hillier and John Morse, Queensland Water Resources Commission for information on water qualities.

Dave Ryan and Doug Bieback, Queensland Electricity Generating Board for information on waters and powerhouse operation.

Jill Gill, Agricultural Chemistry Branch, for water analyses. Phil Sorby and Nev Christianos for assistance with the soil survey. Kelvin Spann and Gerry Robinson for assistance in the field and laboratory experiments.

Staff of the Soils Laboratory, Agricultural Chemistry Branch, for the soil analyses.

Brian Crack, Robin Bruce, Ron McDonald and Kep Coughlan for review and helpful comments on the manuscript, and Ron McDonald for final editing.

Lyn Landers for typing the report.

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APPENDIX 1

Morphological and Analytical Data for Representative Soil Profiles

Soil Profile Class: Wheatlands
Great Soil Group: No suitable group
Parent Material: Alluvium
Topography: Slightly elevated area, plain of low relief.

Map Unit: Wheatlands
Taxonomy Subgroup: Udic Haplustalf
A.M.G. Ref: Zone G56 379440E 7104750N
Air Photo Ref:
Location: Byee Flats Area

Site No: 7
P.P.F.: Gn 3.13

Vegetation: Cleared

Profile Morphology: Surface: Cultivated, hard setting after rain.

Ap_1	0 - 15 cm	Brown (7.5YR 4/3); clay loam, sandy; massive; dry hard; trace manganiferous veins. Gradual to -
B_1	15 - 20	Dull reddish brown (5YR 4/4); sandy clay; moderate medium blocky; dry hard; trace manganiferous veins. Gradual to -
B_{21}	20 - 50	Reddish brown (5YR 4/6) with 15% faint yellow mottle; light medium clay; strong medium blocky; dry hard; trace manganiferous concretions and veins. Gradual to -
B_{22}	50 - 80	Reddish brown (5YR 4/6) with 15% faint yellow mottle; medium clay; strong fine blocky; dry hard; trace manganiferous concretions and veins. Gradual to -
$B_{23}fm$	80 - 100	Dark reddish brown (5YR 3/4) with 20% prominent yellow mottle; light medium clay; strong fine blocky; dry hard; moderate amounts manganiferous concretions and veins. Clear to -
D_1fm	100 - 110	Brown (7.5YR 4/6); sandy clay with small amounts subangular gravel; moderate fine subangular blocky; dry hard; moderate amounts manganiferous concretions and veins. Clear to -
D_2fm	110 - 120	Brown (7.5YR 4/6); light clay; moderate fine blocky; dry hard; moderate amounts of manganiferous concretions and veins. Clear to -
D_3fm	120 - 140	Reddish brown (5YR 4/6); sandy clay with small amounts subangular gravel; moderate fine subangular blocky; dry slightly hard; moderate amounts manganiferous concretions and veins. Clear to -
D_4fm	140 - 150	Reddish brown (5YR 4/8); clay loam, sandy; moderate fine subangular blocky; dry slightly hard; moderate amounts manganiferous veins.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S.	F.S.	Si	C	C.E.C.	Ca^{++}	Mg^{++}	K^+	Na^+	P	K	S	Moisture % A.D.	1/3 bar	15 bar
						Particle Size % O.D.				Exch. Cations m. equiv/100 g O.D.					% O.D.					
16872H	0-10	6.6	.09	.009	.57	38	29	11	22	11	4.1	2.8	1.2	.15	.075	1.77	.012	1.3	16	8
16874H	20-30	7.7	.06	.004	.43	25	23	3	48	18	7.1	5.2	1.5	.13	.064	1.41	.008	2.4	26	17
16877H	50-60	7.5	.08	.002	.30	16	13	2	67	23	8.9	7.2	1.0	.50	.041	0.89	.012	3.8	34	24
16880H	80-90	7.3	.08	.004	.39	23	19	5	52	22	8.7	8.3	.26	.51	.030	1.13	.010	4.2	28	18
16883H	110-120	8.0	.07	.008		29	28	3	33	18	7.3	7.0	.20	.52	.033	1.41	.005	3.6		
16886H	140-150	8.1	.06	.006	.48	49	23	5	23	12	5.4	5.1	.16	.41	.039	1.77	.004	2.3	17	11

Lab.No.	Depth cm	Org. C %	Tot. N %	Acid Extr. P ppm	Bicarb Extr. P ppm	Repl. K m.equiv/100g	Fe D.T.P.A. Extr. ppm	Mn	Cu	Zn	B ppm
16871H	0-10	.66	.06	110	86	.80	30	50	1.2	0.7	
16873H	10-20	.66	.07	105	92	.95					

Soil Profile Class: Weir
Great Soil Group: Black earth
Parent Material: Alluvium
Topography: Levee of Barambah Creek, plain of low relief.

Map Unit: Weir
Taxonomy Subgroup: Udic Chromustert
A.M.G. Ref: Zone G56 384730E 7100920N
Air Photo Ref:
Location: Byee Flats Area

Site No: 1
P.P.F.: Ug 5.15

Vegetation: Cleared

Profile Morphology: Surface: Uncultivated, weakly cracking, hard setting.

A_{11}	0 - 10 cm	Brownish black (10YR 2/2); light medium clay; strong fine blocky; dry hard. Clear to -
A_{12}	10 - 20	Brownish black (10YR 2/2); light medium clay; strong medium blocky; dry hard. Clear to -
B_{21}	20 - 40	Brownish black (10YR 2/2); medium clay; strong medium blocky; dry very hard. Gradual to -
B_{22}	40 - 70	Brownish black (10YR 2/2); medium clay; strong medium lenticular; dry very hard; trace manganiferous concretions. Gradual to -
B_{23}	70 - 90	Brownish black (10YR 3/2); medium clay; strong medium lenticular; dry very hard; trace manganiferous concretions. Clear to -
D_1ca	90 - 120	Dark brown (10YR 3/3); medium clay; strong medium lenticular; dry very hard; small amounts of manganiferous and lime concretions. Gradual to -
D_2ca	120 - 150	Dark brown (10YR 3/3); light medium clay; strong fine blocky, dry very hard; small amounts of manganiferous and lime concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S.	F.S.	Si	C	C.E.C.	Ca^{++}	Mg^{++}	K^+	Na^+	P	K	S	Moisture % A.D.	1/3 bar	15 bar
						Particle Size % O.D.				Exch. Cations m. equiv/100 g O.D.					% O.D.					
16776H	0-10	6.4	.08	.002	.39	2	18	35	42	35	13	11	.66	.89	.123	1.39	.033	3.4	36	20
16778H	20-30	6.7	.09	.004	.53	2	15	24	60	45	17	15	.27	2.9	.103	1.12	.024	4.3	42	23
16781H	50-60	8.2	.30	.034	.55	1	17	19	66	46	19	19	.19	5.6	.050	0.96	.024	4.8	45	25
16784H	80-90	8.8	.43	.048	.57	2	20	22	59	39	17	18	.13	5.4	.043	1.03	.018	3.5	41	23
16787H	110-120	8.7	.40	.042		3	22	18	52	37	15	17	.18	4.3	.053	1.11	.012	3.4		
16790H	140-150	8.8	.48	.045	.58	2	18	23	61	38	17	20	.21	5.3	.049	1.02	.016	4.2	42	23

Lab.No.	Depth cm	Org. C %	Tot. N %	Acid Extr. P ppm	Bicarb Extr. P ppm	Repl. K m.equiv/100g	Fe D.T.P.A. Extr. ppm	Mn	Cu	Zn	B ppm
16775H	0-10	2.9	.10	120+	100+	.72	120	77	2.8	5.2	
16777H	10-20	2.7	.08	120+	100+	.46					

Soil Profile Class: Weir
Great Soil Group: Black earth
Parent Material: Alluvium
Topography: Levee of Barambah Creek, plain of low relief.

Map Unit: Weir
Taxonomy Subgroup: Udic Pellustert
A.M.G. Ref: Zone G56 387800E 7099670N
Air Photo Ref:
Location: Byee Flats Area

Site No: 2
P.P.F.: Ug 5.15

Vegetation: Cleared

Profile Morphology: Surface: Cultivated, weakly cracking, weakly self mulching.

Ap_1	0 - 10 cm	Black (10YR 2/1); light clay; moderate fine crumb; dry slightly hard. Clear to -
Ap_2	10 - 20	Black (10YR 2/1); light clay; moderate fine blocky; dry slightly hard. Clear to -
B_{21}	20 - 40	Black (10YR 2/1); light medium clay; strong medium blocky; dry hard; trace iron segregations. Gradual to -
B_{22}	40 - 60	Brownish black (10YR 3/2); medium clay; strong fine blocky; dry very hard; trace iron segregations. Gradual to -
B_{23}	60 - 90	Brownish black (10YR 3/1); medium clay; strong fine lenticular; dry very hard; trace iron segregations and manganiferous concretions. Clear to -
D_1ca	90 - 120	Dark brown (10YR 3/3); medium clay; strong fine lenticular; dry very hard; small amounts of manganiferous and lime concretions. Gradual to -
D_2ca	120 - 150	Dark brown (7.5YR 3/3) medium clay; strong medium blocky; dry very hard; small amounts manganiferous and lime concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S.	F.S.	Si	C	C.E.C.	Ca^{++}	Mg^{++}	K^+	Na^+	P	K	S	Moisture % A.D.	1/3 bar	15 bar
						Particle Size % O.D.				Exch. Cations m. equiv/100 g O.D.					% O.D.					
16792H	0-10	6.2	.15	.012	.40	3	30	36	34	29	11	9.7	.48	.6	.126	1.44	.027	3.0	29	14
16794H	20-30	6.5	.06	.005	.43	3	31	35	35	28	10	9.2	.18	1.0	.117	1.44	.016	3.3	31	15
16797H	50-60	7.6	.19	.023	.58	2	27	24	49	37	17	16	.18	2.8	.085	1.22	.014	3.9	37	20
16800H	80-90	8.5	.35	.038	.54	2	29	24	48	38	18	17	.18	3.7	.056	1.24	.014	3.5	37	19
16803H	110-120	8.9	.47	.052		7	31	13	44	34	14	14	.21	3.9	.065	1.40	.009	3.5		
16806H	140-150	8.6	.51	.066	.64	4	35	18	45	32	13	13	.24	3.8	.074	1.47	.008	3.6	34	18

Lab.No.	Depth cm	Org. C %	Tot. N %	Acid Extr. P ppm	Bicarb Extr. P ppm	Repl. K m.equiv/100g	Fe D.T.P.A. Extr. ppm	Mn	Cu	Zn	B ppm
16791H	0-10	2.2	.16	120+	100+	.39	84	50	2.0	2.2	
16793H	10-20	1.9	.16	120+	100+	.38					

Soil Profile Class: Byee
Great Soil Group: Black earth
Parent Material: Alluvium
Topography: Drainage line from surrounding hills, plain of low relief.
Map Unit: Byee
Taxonomy Subgroup: Udic Chromustert
A.M.G. Ref: Zone G56 381610E 7101390N
Air Photo Ref:
Location: Byee Flats Area
Site No: 4
P.P.F.: Ug 5.15

Vegetation: Cleared

Profile Morphology: Surface: Uncultivated, moderately self mulching, strongly cracking.

A_{11}	0 - 2 cm	Brownish black (10YR 3/2); medium clay; strong fine crumb; dry hard. Clear to -
A_{12}	2 - 10	Brownish black (10YR 3/2); medium clay; strong fine blocky; dry very hard. Gradual to -
B_{21}	10 - 30	Brownish black (10YR 2/2); medium clay; strong fine blocky; dry very hard. Gradual to -
B_{22}	30 - 60	Black (10YR 2/1); medium clay; strong fine blocky; dry very hard; trace iron segregations and manganiferous concretions. Gradual to -
B_{23}	60 - 120	Brownish black (10YR 2/2); medium clay; strong medium lenticular; dry very hard; small amounts manganiferous concretions. Gradual to -
B_{24}	120 - 130	Brownish black (10YR 2/3); medium clay; strong fine lenticular; dry very hard; small amounts manganiferous concretions.
D_{1}ca	130 - 150	Dark brown (7.5YR 3/3); medium clay; strong medium blocky; dry very hard; small amounts manganiferous and lime concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S.	F.S.	Si	C	C.E.C.	Ca^{++}	Mg^{++}	K^+	Na^+	P	K	S	Moisture % A.D.	1/3 bar	15 bar
						Particle Size % O.D.				Exch. Cations m. equiv/100 g O.D.					% O.D.					
16824H	0-10	6.6	.11	.002	.34	3	11	16	70	67	21	33	.18	1.7	.063	0.21	.034	8.8	57	32
16826H	20-30	7.1	.04	.002	.36	1	13	13	74	63	19	31	.18	1.6	.047	0.20	.022	7.8	55	31
16829H	50-60	7.0	.08	.008	.40	1	13	10	73	64	19	34	.26	2.3	.054	0.23	.014	6.8	59	33
16832H	80-90	7.4	.17	.021	.42	1	15	13	72	65	18	37	.22	3.1	.049	0.24	.013	6.7	57	32
16835H	110-120	8.3	.22	.026		3	12	5	75	68	19	43	.14	3.8	.027	0.19	.010	7.7		
16838H	140-150	8.9	.31	.024	.49	7	15	14	65	54	15	38	.15	3.5	.033	0.24	.007	6.6	47	28

Lab.No.	Depth cm	Org. C %	Tot. N %	Acid Extr. P ppm	Bicarb Extr. P ppm	Repl. K m.equiv/100g	Fe	Mn	Cu	Zn	B ppm
							D.T.P.A. Extr. ppm				
16823H	0-10	2.2	.20	17	26	.26	80	58	3.8	1.6	
16825H	10-20	2.7	.22	10	26	.25					

Soil Profile Class: Byee
Great Soil Group: Black earth
Parent Material: Alluvium
Topography: Levee backslope position, plain of low relief.
Map Unit: Byee
Taxonomy Subgroup: Udic Chromustert
A.M.G. Ref: Zone G56 387200E 7099730N
Air Photo Ref:
Location: Byee Flats Area
Site No: 10
P.P.F.: Ug 5.15

Vegetation: Cleared

Profile Morphology: Surface: Cultivated, moderately self mulching, moderately cracking.

Ap_1	0 - 2 cm	Brownish black (10YR 3/2); medium clay; moderate fine crumb, dry very hard. Clear to -
Ap_2	2 - 20	Brownish black (10YR 3/2); medium clay, strong fine blocky; dry very hard. Clear to -
B_{21}	20 - 50	Brownish black (10YR 2/2); medium clay, strong fine blocky; dry very hard, trace iron segregations. Gradual to -
B_{22}	50 - 80	Brownish black (10YR 2/2); medium heavy clay, strong coarse lenticular; dry very hard; trace iron segregations and manganiferous concretions. Gradual to -
B_{23}	80 - 110	Brownish black (10YR 3/1); medium heavy clay; strong medium lenticular; very hard; small amounts iron segregations and manganiferous concretions. Gradual to -
B_{24}	110 - 140	Brownish black (10YR 3/1); medium heavy clay; strong medium blocky, dry very hard; small amounts iron segregations and manganiferous concretions. Gradual to -
B_{25}	140 - 150	Brown (7.5YR 4/3); medium heavy clay; strong medium blocky; dry very hard; small amounts manganiferous concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S.	F.S.	Si	C	C.E.C.	Ca^{++}	Mg^{++}	K^+	Na^+	P	K	S	Moisture % A.D.	1/3 bar	15 bar
						Particle Size % O.D.				Exch. Cations m. equiv/100 g O.D.					% O.D.					
16920H	0-10	6.4	.09	.008	.56	4	17	24	51	37	12	14	.65	.94	.115	1.25	.019	4.0	35	20
16922H	20-30	6.7	.13	.014	.62	3	17	30	52	40	16	16	.32	1.7	.087	1.28	.011	4.2	39	22
16925H	50-60	7.3	.43	.044	.54	1	11	21	63	49	21	21	.25	3.2	.089	1.05	.011	5.6	46	26
16928H	80-90	7.9	.34	.042	.63	1	11	20	63	48	21	22	.20	3.7	.062	1.08	.009	6.0	48	26
16931H	110-120	8.1	.37	.041		2	14	19	63	48	20	22	.20	3.7	.055	1.12	.007	5.7		
16934H	140-150	8.2	.30	.040	.70	5	21	18	51	42	16	19	.30	3.2	.053	1.26	.006	4.2	41	22

Lab.No.	Depth cm	Org. C %	Tot. N %	Acid Extr. P ppm	Bicarb Extr. P ppm	Repl. K m.equiv/100g	Fe	Mn	Cu	Zn	B ppm
							D.T.P.A. Extr. ppm				
16919H	0-10	1.6	0.13	120+	100+	.61	88	63	3.0	1.0	
16921H	10-20	1.4	0.11	120+	100+	.44					

Soil Profile Class: Eastgate
Great Soil Group: No suitable group. Similarities with black earth.
Parent Material: Alluvium
Topography: Intermediate position, plain of low relief.
Map Unit: Eastgate
Taxonomy Subgroup: Udertic Paleustalf
A.M.G. Ref: Zone G56 38499E 7804630N
Air Photo Ref:
Location: Byee Flats Area
Site No: 8
P.P.F.: Ug 3.1

Vegetation: Cleared

Profile Morphology: Surface: Uncultivated, hard setting, moderately cracking.

A_1	0 - 10 cm	Brownish black (10YR 3/2); light medium clay, moderate medium blocky; dry very hard; trace manganiferous concretions. Clear to -
A_2	9 - 10 cm	As above with sporadic bleach. Clear to -
B_{21}	10 - 20	Brownish black (10YR 3/2); medium clay; strong medium blocky; dry very hard; trace of iron segregations and manganiferous concretions. Gradual to -
B_{22}	20 - 50	Brownish black (10YR 3/2); medium clay; strong fine blocky; dry very hard; trace of iron segregations and manganiferous concretions. Clear to -
B_{23}ca	50 - 80	Brown (7.5YR 4/3); medium clay; strong fine blocky; dry very hard; small amounts manganiferous and lime concretions. Gradual to -
B_{24}ca	80 - 110	Brown (7.5YR 4/3); medium clay; strong fine blocky; dry very hard; small amounts manganiferous concretions; moderate amounts lime concretions. Clear to -
D_1	110 - 150	Brown (7.5YR 4/3); light medium clay; moderate medium blocky; dry hard; small amounts manganiferous veins and lime concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S.	F.S.	Si	C	C.E.C.	Ca^{++}	Mg^{++}	K^+	Na^+	P	K	S	Moisture % A.D.	1/3 bar	15 bar
						Particle Size % O.D.				Exch. Cations m. equiv/100 g O.D.					% O.D.					
16888H	0-10	6.2	.09	.006	.50	9	21	37	35	30	5.3	8.3	.87	1.8	.114	1.15	.027	3.7	31	16
16890H	20-30	7.8	.25	.032	.75	2	13	17	63	47	13	20	.24	7.9	.054	0.81	.028	5.1	44	25
16893H	50-60	8.9	.97	.125	.90	3	15	14	67	45	13	21	.24	12	.071	0.98	.017	5.5	46	26
16896H	80-90	9.3	.82	.079	.89	11	18	17	52	39	[illegible]	19	.26	10	.132	1.25	.016	5.6	39	22
16899H	110-120	9.3	.70	.069		2	21	[illegible]	49	40	11	18	.28	10	.149	1.36	.009	6.2		
16902H	140-150	9.2	.58	.060	.84	1	31	21	45	36	9.5	17	.23	10	.133	1.40	.004	6.3	38	20

Lab.No.	Depth cm	Org. C %	Tot. N %	Acid Extr. P ppm	Bicarb Extr. P ppm	Repl. K m.equiv/100g	Fe	Mn	Cu	Zn	B ppm
							D.T.P.A. Extr. ppm				
16887H	0-10	3.0	.23	85	100	.45	120	66	1.8	2.0	
16889H	10-20	2.7	.18	66	100	.56					

Soil Profile Class: Eastgate
Great Soil Group: Black earth
Parent Material: Alluvium
Topography: Levee backslope position, plain of low relief.

Map Unit: Eastgate
Taxonomy Subgroup: Udic Chromustert
A.M.G. Ref: Zone G56 380620E 7104250N
Air Photo Ref:
Location: Byee Flats Area

Site No: 6
P.P.F.: Ug 5.15

Vegetation: Cleared

Profile Morphology: Surface: Cultivated, weakly self mulching, moderately cracking.

Ap1	0 - 2 cm	Brownish black (10YR 2/2); medium clay; strong fine crumb; dry extremely hard; trace manganiferous concretions. Clear to -
Ap2	2 - 10	Brownish black (10YR 2/2); medium clay; strong medium blocky, dry extremely hard; trace manganiferous concretions. Gradual to -
B21	10 - 30	Brownish black (10YR 3/2); medium clay; strong fine blocky, dry very hard; trace manganiferous concretions. Gradual to -
B22	30 - 50	Brown (7.5YR 4/3); medium clay; strong fine blocky; dry very hard; trace manganiferous concretions. Clear to -
B23ca	50 - 80	Brown (7.5YR 4/3); medium clay; strong fine lenticular; dry very hard; small amounts manganiferous and lime concretions. Gradual to -
B24ca	80 - 140	Brown (7.5YR 4/3); medium clay; strong fine lenticular; dry very hard; small amounts manganiferous concretions; moderate amounts lime concretions. Clear to -
B25ca	140 - 150	Brown (7.5YR 4/3); light medium clay; strong fine blocky; dry hard; small amounts manganiferous and lime concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S. Particle Size % O.D.	F.S.	Si	C	C.E.C. Exch. Cations m. equiv/100 g O.D.	Ca^{++}	Mg^{++}	K^+	Na^+	P % O.D.	K	S	Moisture % A.D.	1/3 bar	15 bar
16856H	0-10	7.2	.24	.027	.75	4	18	25	54	41	10	17	.34	5.8	.085	0.93	.024	5.1	39	24
16858H	20-30	8.4	.41	.053	.80	2	14	16	66	47	13	21	.16	9.7	.062	0.82	.028	6.7	45	28
16861H	50-60	9.1	.86	.095	.91	5	16	17	61	45	16	26	.15	5.8	.069	0.92	.017	4.5	44	27
16864H	80-90	9.2	.85	.091	.87	7	15	20	56	42	9.0	19	.28	9.8	.131	1.19	.008	4.6	44	25
16867H	110-120	9.2	.87	.099		3	12	20	62	47	12	21	.27	11	.108	1.04	.007	6.4		
16870H	140-150	9.0	.70	.085	.90	4	19	19	56	41	9.9	19	.27	10	.098	1.25	.005	5.4	40	23

Lab.No.	Depth cm	Org. C %	Tot. N	Acid Extr. P ppm	Bicarb	Repl. K m.equiv/100g	Fe D.T.P.A. Extr. ppm	Mn	Cu	Zn	B ppm
16855H	0-10	1.4	.13	53	42	.26	50	52	2.6	0.6	
16857H	10-20	1.4	.12	50	38	.20					

Soil Profile Class: Gueena
Great Soil Group: Grey clay
Parent Material: Alluvium
Topography: Levee backswamp position, plain of low relief.

Map Unit: Gueena
Taxonomy Subgroup: Udic Chromustert
A.M.G. Ref: Zone G56 386900E 7099750N
Air Photo Ref:
Location: Byee Flats Area

Site No: 9
P.P.F.: Ug 5.24

Vegetation: Woodland of blue gum

Profile Morphology: Surface: Uncultivated, moderately self mulching, moderately cracking.

A11	0 - 2 cm	Brownish black (10YR 2/2); with 10% faint brown mottle; medium clay; moderate fine crumb; dry very hard; small amounts manganiferous concretions. Clear to -
A12	2 - 10	Brownish black (10YR 2/2); with 10% faint brown mottle; medium clay; strong medium blocky; dry very hard; small amounts manganiferous concretions. Clear to -
B21	10 - 30	Greyish yellow brown (10YR 4/2); with 15% distinct brown mottle; medium clay; strong fine blocky; dry very hard; small amounts manganiferous concretions. Gradual to -
B22	30 - 80	Dark greyish yellow (2.5Y 4/2); medium heavy clay; strong medium lenticular; dry very hard; small amounts manganiferous concretions. Gradual to -
B23	80 - 110	Yellowish grey (2.5Y 4/1); medium heavy clay: strong fine lenticular; dry very hard; small amounts manganiferous concretions. Gradual to -
B24	110 - 130	Brownish grey (10YR 4/1); medium clay; strong fine blocky; dry very hard; small amounts iron segregations and manganiferous concretions.
B25	130 - 150	Yellowish grey (2.5Y 4/1); medium clay; strong fine blocky; dry very hard; small amounts iron segregations and manganiferous concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S. Particle Size % O.D.	F.S.	Si	C	C.E.C. Exch. Cations m. equiv/100 g O.D.	Ca^{++}	Mg^{++}	K^+	Na^+	P % O.D.	K	S	Moisture % A.D.	1/3 bar	15 bar
16904H	0-10	6.9	.10	.003	.31	4	6	10	73	53	18	25	.83	1.1	.057	0.60	.039	7.8	50	29
16906H	20-30	7.4	.10	.006	.33	3	7	4	79	54	20	27	.27	1.6	.036	0.45	.019	7.7	52	31
16909H	50-60	7.7	.30	.030	.46	3	7	2	80	54	17	28	.18	2.7	.025	0.44	.011	8.5	54	31
16912H	80-90	8.1	.65	.083	.47	3	8	4	78	53	17	30	.16	3.8	.020	0.50	.007	8.2	52	31
16915H	110-120	8.2	.84	.104		2	7	12	73	54	17	30	.16	4.6	.018	0.67	.006	8.0		
16918H	140-150	8.3	.72	.095	.63	2	7	10	73	56	16	33	.17	4.9	.018	0.63	.005	7.8	51	30

Lab.No.	Depth cm	Org. C %	Tot. N	Acid Extr. P ppm	Bicarb	Repl. K m.equiv/100g	Fe D.T.P.A. Extr. ppm	Mn	Cu	Zn	B ppm
16903 H	0-10	2.9	.25	28	29	.46	90	60	3.6	1.3	
16905H	10-20	2.6	.26	12	16	.62					

Soil Profile Class: Gueena
Great Soil Group: Grey clay
Parent Material: Alluvium
Topography: Broad drainage line, plain of low relief.

Map Unit: Gueena
Taxonomy Subgroup: Udic Chromustert
A.M.G. Ref: Zone G56 381060E 7103080N
Air Photo Ref:
Location: Byee Flats Area

Site No: 5
P.P.F.: Ug 5.24

Vegetation: Cleared.

Profile Morphology: Surface: Cultivated moderately self mulching, moderately cracking.

Ap1	0 - 2 cm	Brownish black (10YR 3/2); with 10% faint brown mottle; medium heavy clay; strong medium crumb; dry very hard; small amounts manganiferous concretions. Clear to -
Ap2	2 - 10	Brownish black (10YR 3/2) with 10% faint brown mottle; medium heavy clay; strong medium blocky; dry very hard; small amounts manganiferous concretions. Clear to -
B21	10 - 40	Greyish yellow brown (10YR 4/2) with 15% distinct brown mottle; medium heavy clay; strong fine blocky; dry very hard; small amounts manganiferous concretions. Gradual to -
B22	40 - 60	Greyish yellow brown (10YR 4/2); medium heavy clay; strong fine lenticular; dry very hard; small amounts manganiferous concretions. Gradual to -
B23	60 - 100	Dark greyish yellow (2.5Y 4/2); medium heavy clay; strong fine lenticular; dry very hard; small amounts manganiferous concretions. Clear to -
B24ca	100 - 150	Brown (10YR 4/3); medium heavy clay; strong medium blocky; dry very hard; small amounts manganiferous and lime concretions.

Laboratory Data:

Lab.No.	Depth cm	pH 1:5	E.C.(1:5) $mScm^{-1}$	Cl ppm	Dispersion Ratio (R_1)	C.S. Particle Size % O.D.	F.S.	Si	C	C.E.C. Exch. Cations m. equiv/100 g O.D.	Ca^{++}	Mg^{++}	K^+	Na^+	P % O.D.	K	S	Moisture % A.D.	1/3 bar	15 bar
16840H	0-10	6.3	.13	.007	.43	3	10	22	65	53	16	21	.80	.96	.088	0.88	.033	6.8	47	28
16842H	20-30	7.2	.13	.011	.71	3	10	18	69	49	16	22	.24	2.4	.060	0.82	.013	9.3	51	30
16845H	50-60	7.8	.19	.022	.85	3	15	21	61	42	14	21	.18	4.1	.055	0.93	.009	4.8	45	26
16848H	80-90	8.2	.42	.037	.89	1	13	19	63	47	14	24	.21	6.1	.059	0.97	.011	5.1	45	27
16851H	110-120	9.1	.60	.052		4	17	18	57	43	14	23	.18	6.7	.093	1.05	.013	5.4		
16854H	140-150	9.0	.66	.072	.93	2	15	24	59	44	13	24	.28	7.7	.133	1.18	.010	5.6	43	26

Lab.No.	Depth cm	Org. C %	Tot. N	Acid Extr. P ppm	Bicarb	Repl. K m.equiv/100g	Fe D.T.P.A. Extr. ppm	Mn	Cu	Zn	B ppm
16839H	0-10	1.7	.19	35	61	.50	96	57	3.2	1.0	
16841H	10-20	2.1	.19	45	89	.66					

APPENDIX 2

Vegetation - Common and Specific Names

Trees:

Blue gum	*Eucalyptus tereticornis*
Broad leaved ironbark	*E. siderophloia*
Gum-topped box	*E. moluccana*
Poplar box	*E. populnea*
Rough-barked apple	*Angophora floribunda*

Shrubs:

Weeping red bottle-brush	*Callistemon viminalis*

Grasses:

Barnyard grass	*Echinochloa colona*
Blue grasses	*Bothrichloa and Dichanthium sp.*
Couch	*Cynodon dactylon*
Love grasses	*Eragrostis spp.*
Paspalum	*Paspalum dilatatum*
Rhodes grass	*Chloris gayana*

APPENDIX 3

Soil Analytical Methods

Sample Preparation

Samples were dried in a forced air draught at 40°C and ground to less than 2 mm. Soil tests were carried out on the <2 mm soil except where indicated. Results are reported on an air dry basis except where otherwise stated.

Electrical Conductivity

A 1:5 soil deionized water suspension was shaken for one hour and the electrical conductivity (E.C.) measured at 25°C.

pH

The soil water suspension used for determination of electrical conductivity was used for pH. pH was determined with glass and calomel electrodes and a Townson Specific Ion/pH meter.

Chloride

After electrical conductivity and pH were determined the same soil water suspension was used to measure chloride. The specific ion chloride electrode was used according to Haydon, Williams and Ahern (1974).

Organic Carbon

The wet combustion method of Walkley and Black (1934) was used on finely ground soil (<80 mesh). Results were obtained using the colorimetric method of Sims and Haby (1971). Results are reported as per cent carbon (Walkley and Black values) on an oven dry basis.

Total Nitrogen

The sample was finely ground. Selenium catalyst was used in the Kjeldahl method. An Auto Analyser system was used for estimation of ammonium in the digests. Results are reported as per cent nitrogen on an oven dry basis.

Extractable Phosphorus

Acid extractable phosphorus was determined by the method of Kerr and von Stieglitz (1938) by extracting with 0.01 N H_2SO_4 for 16 hours. An auto analyser system was used to read the extracts using the Murphy and Riley (1962) colour development method.

Bicarbonate extractable phosphorus (Colwell 1963) was extracted with 0.5 M sodium bicarbonate pH 8.5 and shaken for 16 hours. The extracts were read on an auto analyser system similar to the acid extractable phosphorus.

Total Phosphorus, Potassium and Sulphur

About 3 g of soil sample were finely ground in a 'Shatter-box' mill and pressed into a pellet as described by Norrish and Hutton (1964). The pellet was then exposed to a beam of X-rays in a Philips 1410 vacuum X-ray spectrograph. Simple linear calibration was used to obtain percentage phosphorus, potassium and sulphur from fluorescent intensities.

Exchangeable Cations

A method similar to that reported by Loveday (1974) was used.

Prewashing was done with 60% ethanol. Exchangeable cations were removed with 1 N NH_4Cl at pH 8.5 in 60% ethanol. Absorbed ammonium was removed with 1 N sodium sulphate.

Ammonium N and Cl were determined in milliequivalents on an auto analyser using colorimetric methods. The difference was reported as the C.E.C. on an oven dry basis.

Particle Size Distribution

Particle size distribution was determined using a modification of the hydrometer method of Day (1956).

Moisture Characteristics

The gravimetric water content of the soils was measured on ground samples equilibrated on ceramic pressure plates at 2 potentials, $-^1/_3$ bar and -15 bar, after the method of McIntyre (1974).

Results are reported as g/100 g O.D. soil. Available water is calculated as the difference between the gravimetric water contents at $-^1/_3$ and -15 bar.

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APPENDIX 4

Interpretation of Soil Analytical Results

The interpretations are of a general nature and do not refer to any one particular crop.

Extractable Phosphorus

	P ($N/100\ H_2SO_4$) extraction	($M/2\ NaHCO_3$) extraction
Very low	<10 ppm	<11 ppm
Low	11 - 20 ppm	12 - 20 ppm
Fair	21 - 35 ppm	21 - 30 ppm
Very Fair	36 - 45 ppm	31 - 40 ppm
High	46 - 100 ppm	>40 ppm
Very High	>100 ppm	

Source: Agricultural Chemistry Branch, Queensland Department of Primary Industries.

Total Nitrogen (Kjeldahl)

	N%
Very low	<0.05
Low	0.05 - 0.09
Fair	0.10 - 0.14
Very Fair	0.15 - 0.24
High	0.25 - 0.49
Very High	>0.50

Source: Agricultural Chemistry Branch, Queensland Department of Primary Industries.

Soluble Salts (1:5 soil, water suspension)

Cl %		Elect. Conductivity ($mS\ cm^{-1}$)
<0.01	Very low	<0.15
.011 - .030	Low	0.16 - 0.45
.031 - .060	Medium	0.46 - 0.90
.061 - .20	High	0.91 - 2.0
>.20		>2.0

Source: Agricultural Chemistry Branch, Queensland Department of Primary Industries.

Replaceable Potassium 0.05N HCl extraction

	K meq. %
Very low	<0.15
Low	0.15 - 0.20
Fair	0.21 - 0.30
Very Fair	0.31 - 0.50
High	>0.50

Source: Agricultural Chemistry Branch, Queensland Department of Primary Industries.

Sulphur

Sites with soil containing <0.01% total sulphur were commonly found to show fertilizer responses on a range of Queensland soils.

Source: Andrew, Crack and Rayment (1974).

Organic Carbon (Walkley and Black Values)

Very low	<0.59
Low	0.60 - 1.75
Medium	1.76 - 2.9
High	3.0 - 5.8
Very High	>5.8

Many Australian soils have been recorded in the 1.2 to 2.3 range.

Source: Agricultural Chemistry Branch, Queensland Department of Primary Industries.

Calcium and Magnesium

Calcium	<2 meq/100 g	low
	>2 meq/100 g	adequate
Magnesium	<1.7 meq/100 g	low
	>1.7 meq/100 g	adequate

Source: Consolidated Fertilizers Interpretation Manual (1977)

Copper, Zinc, Manganese and Iron

Critical levels of DTPA - extractable micronutrients for sensitive crops.

Nutrient	Deficient	Marginal	Adequate
	- ppm extracted from soils -		
Zn	0.5	0.5 - 1.0	1.0
Fe	2.5	2.5 - 4.5	4.5
Mn	1.0		1.0
Cu	0.2		0.2

Source: Viets and Lindsay (1973).

A rough guide when suspecting toxicity would be:-

Mn	>500 ppm
Zn	>15 ppm
Cu	>15 ppm

Manganese toxicity may be complicated by the soil pH, and induced zinc and iron deficiency.

Available Water (water held between $-^1/_3$ bar and -15 bar water potentials)

<5%	v. low
5.1 - 8.0	low
8.1 - 12	medium
12.1 - 15	high
>15	v. high

Dispersion Ratio R_1

<0.6	low dispersion
0.6 - 0.8	moderate dispersion
>0.8	high dispersion

Source: Agricultural Chemistry Branch, Queensland Department of Primary Industries.

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APPENDIX 5

Conventions Used in the Description of the Morphology of Soil Profile Classes

(a) The pH profiles are based on field determinations made at 5, 30, 60, 90, 120 and 150 cm depths.

(b) Principal Profile Forms are listed in order of decreasing frequency of occurrence.

(c) Colour codes are those of Oyama and Takehara (1967) while colour nomenclature is that of R.C. McDonald (personal communication) based on the Value/Chroma rating system of Northcote (1971) and utilizing the following table:

Value/Chroma 2a = 4/1 - 4/2 to 6/1 - 6/2

Value/Chroma 2b = 5/3 - 5/4 to 6/3 - 6/4

Value/Chroma Rating	1	2a	2b	4	5
Hue					
10R	dark	red-grey	red-brown	red	red
2.5YR	dark	grey-brown	red-brown	red	red
5YR	dark	grey-brown	brown	red-brown	red-brown
7.5YR	dark	grey-brown	brown	yellow-brown	brown
10YR	dark	grey	yellow-brown	yellow	brown
2.5Y	dark	grey	yellow-grey	yellow	olive-brown
5Y	dark	grey	yellow-grey	yellow	olive

(d) Self mulch:

Weak = <1 cm of poorly developed self mulch

Moderate = 1 - 2 cm of discrete aggregates breaking to granular peds.

Strong = >2 cm of discrete aggregates breaking to granular peds.

(e) Mottling: Weak = <10%

Moderate = 10 - 25%

Strong = >25%

(f) Gilgai: Weak = 5 - 10 cm vertical interval

Moderate = 10 - 30 cm vertical interval

(g) Structure:

As per Soil Survey Staff (1951).
Lenticular size categories defined as for prismatic.

(h) Frequency of occurrence:

Frequently = on 30 - 90% of occasions

Occasionally = on 10 - 30% of occasions

References

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APPENDIX 6

Land Capability Classification

Soil Profile Class	*Land Class*	*Limitation Sub-Class*
Wheatlands	3	t3, pc3
Tregear	4	t3, pb3, so3
Terrace	4	f4
Weir	2	t2
Byee	1	
Eastgate	3	t2, sa3, so3
Kaber	3	t2, sa3, so3
Gueena	2	f2, g2

PROVISIONAL LAND CAPABILITY CLASSIFICATION

Limitation	Criteria for Degree of Limitation	Capability Class (If Sole Limiting Factor)	Sub-Class Symbol
Slope	0.1 - 0.5%	1	-
	0.5 - 1.0%	2	t2
	1.0 - 2%	3	t3
	2% - 4.0%	4	t4
Susceptibility to Flooding	No flooding	1	-
	Occasional flooding	2	f2
	Moderate flooding	3	f3
	Frequent flooding	4	f4
Microrelief	No gilgai	1	-
	Vertical interval of gilgai		
	<25 cm	2	g2
	25 - 60 cm	3	g3
	>60 cm	4	g4

Limitation	Criteria for Degree of Limitation	Capability Class (If Sole Limiting Factor)	Sub-Class Symbol
Stoniness	No cobble, stone or rock	1	
	Loose cobble and stone averaging 25-125 tonnes per hectare	3	r3
	Loose cobble and stone averaging 125-250 tonnes per hectare	4	r4
	Rock, cobble and stone averaging >250 tonnes per hectare	5	r5
Soil physical properties affecting plant growth and management	(i) B horizon or sub-soil depth Average depth to hard B horizon or sub-soil with consistence dry extremely hard		
	20-45 cm	3	pb3
	<20 cm	4	pb4
	(ii) Surface crust Hardsetting surface with consistence*		
	dry hard	3	pc3
	dry very hard	4	pc4
	(iii) Distribution of soil type Soils, with surface textures differing more than one field texture group**, which have boundaries occurring, on the average,		
	150-300 m apart	3	pd3
	<150 m apart	4	pd4
	(iv) Texture of soils Soils with textures in field texture group 1. Sands, or 2. Sandy Loams, to depths		
	45-90 cm	3	pt3
	>90 cm	4	pt4
	(v) Gravel beds Gravel beds >15 cm thick and surface of gravel beds <45 cm from soil surface	4	pg4

* U.S.D.A. Soil Survey Manual (1951)

** Northcote (1971)

Limitation	Criteria for Degree of Limitation		Capability Class (If Sole Limiting Factor)	Sub-Class Symbol
Effective Depth	Deep	>100 cm	1	-
	Mod. deep	60-100 cm	2	d2
	Mod. shallow	45-60 cm	3	d3
	Shallow	25-45 cm	4	d4
	Very shallow	<25 cm	5	d5
Salinity and Sodicity	Electrical conductivity at 25°C of the 1:5 suspension is greater than 1 mS cm^{-1} at depths,			
	30-90 cm		3	sa3
	<30 cm		4	sa4
	Exchangeable sodium percentage of 15 at depths,			
	30-90 cm		3	so3
	<30 cm		4	so4

Factor Interactions

Cases arise where there may be interaction between limiting factors. It is proposed that where there are more than two Class III limitations that the land concerned be placed in Capability Class IV.

LAND CLASSES

Irrigated Land Use

The following are modified versions of land classes as defined by the United States Bureau of Reclamation (1951).

CLASS 1 - ARABLE

Lands that are highly suitable for irrigation farming, being capable of producing sustained and relatively high yields of a wide range of climatically adapted crops at reasonable cost. They are smooth lying with gentle slopes. The soils are deep and of medium to fairly fine texture with mellow, open structure allowing easy penetration of roots, air and water and having free drainage yet good available moisture capacity. These soils are free from harmful accumulations of soluble salts or can be readily reclaimed. Both soil and topographic conditions are such that no specific drainage requirements are anticipated, minimum erosion will result from irrigation and land development can be accomplished at relatively low cost.

CLASS 2 - ARABLE

This class comprises lands of moderate suitability for irrigation farming, being measurably lower than Class 1 in productive capacity. They are not so desirable nor of such high value as lands of Class 1 because of certain correctible or non-correctible limitations. They may have a lower available moisture capacity, as indicated by coarse texture or limited soil depth; they may be only slowly permeable to water because of clay layers in the subsoil; or they also may be moderately saline which may limit productivity or involve moderate costs for leaching. Topographic limitations include uneven surface requiring moderate costs for levelling, short slopes requiring shorter length of runs, or steeper slopes necessitating special care and greater costs to irrigate and prevent erosion. Farm drainage may be required at a moderate cost or loose rock or woody vegetation may have to be removed from the surface. Any one of the limitations may be sufficient to reduce the lands from Class 1 to Class 2 but frequently a combination of two or more of them is operating.

CLASS 3 - ARABLE

Lands that are suitable for irrigation development but are of restricted suitability because of greater deficiencies in the soil, topographic, or drainage characteristics than described for Class 2 lands. They may have good topography, but because of inferior soils have restricted adaptability, require larger amounts of irrigation water or special irrigation practices and demand greater fertilization or more intensive soil improvement practices. They may have uneven topography, moderate to high concentration of salts or restricted drainage, amenable to correction but only at relatively high costs. Generally, greater risk may be involved in farming Class 3 lands than better classes of land, but under proper management they are expected to have adequate productivity.

CLASS 4 - LIMITED ARABLE OR SPECIAL USE

Lands that have an excessive, specific deficiency or deficiencies susceptible to correction at high cost; or they may have one or more excessive, non-correctible deficiencies thereby limiting their utility to pasture or other relatively permanent crops. The deficiency may be inadequate drainage, excessive salt content requiring extensive leaching, unfavourable position allowing periodic flooding or making water distribution and removal very difficult, rough topography, excessive quantities of loose rock on the surface or in the plough zone. On these lands special economic and agronomic and/or engineering studies are required to show they are capable or sustained production.

CLASS 5 - NON-ARABLE

Lands in this Class are non-arable under existing conditions. They have specific soil deficiencies such as shallowness or excessive rock.

Reference

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