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STUDIES ON THE GILGAIED CLAY SOILS (Ug 5·2) OF THE HIGHWORTH LAND SYSTEM IN EAST-CENTRAL QUEENSLAND

1. CHEMICAL CHARACTERISTICS

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SUMMARY

Some chemical and physical properties of the gilgaied clays of the Highworth land system in east-central Queensland have been described. Data for surface and profile increments are presented and discussed. Differences in soil properties were found between three distinct areas. Major features of the soils are the high soluble salt content in the subsoil, high exchangeable sodium levels and acid pH trend. Extractable phosphorus values in the surface are highly variable; exchangeable potassium values indicate sufficiency for plant growth. Some differences were noted in soil properties between virgin, cleared and cultivated sites.

I. INTRODUCTION

In the Dawson-Fitzroy area of east-central Queensland, there are large areas of soil previously referred to as deep gilgaied clay soils (Isbell 1962) which are the most extensive and uniform group of soils of the brigalow lands. Their most striking feature is a generally moderate to strong development of gilgai microrelief (Isbell 1962). These soils are grey clays (Stace *et al* 1968) and were grouped in a regional report as the Pegunny soil family of the Highworth land system (Speck *et al* 1968). They occupy approximately 45% of this land system which covers approximately 311 000 ha in the Dawson-Fitzroy area.

Present land use on these soils is beef production on improved pastures, with some cropping for grain and for cattle fattening. The degree of gilgai development usually governs the extent of cultivation. The gilgaied clays are regarded as a uniform group by farmers, extension officers, research workers and various bodies responsible for development controls and valuation.

There is little detailed information available to characterize the chemical or physical status of gilgaied clays in central Queensland. Morphological and analytical data are available only for a limited number of sites in the Biloela, Wowan and Moura districts (Reeve, Isbell and Hubble 1963) and the Rolleston, Foxleigh and Lake Galilee areas (Gunn 1966).

Our paper describes some chemical and physical properties of the gilgaied clays of the Highworth land system in the Callide and Dawson Valleys and areas to the west of the Dawson river (subsequently called the Pegunny area) (figure 1). A second paper gives the results of nutrient glasshouse experiments conducted on the same soils.

II. ENVIRONMENT

Climate

The climate of the Dawson-Fitzroy area has been described by Fitzpatrick (1968). Mean annual rainfall of the area studied ranges from 680 to 760 mm with most receiving less than 700 mm. As in most of northern Australia, rainfall shows a marked summer dominance with more than three-quarters falling during October to March inclusive. Variability throughout the year is high.

Mean daily maximum temperature ranges from approximately 21°C in midwinter to 32°C or slightly higher in midsummer. Heat waves are not common. However, periods of 3 days with temperatures above 38°C may occur between December and January. Frosts are common in the winter months with the highest incidence in June, July, and August. At Biloela, the mean number of days with temperatures below 2°C is 8·8, 11·7 and 10·5 for these months respectively.

Evaporation is high with an annual mean of 1 587 mm at Biloela. The most important climatic factors that influence land use are moisture deficits and extremes of temperatures (Speck *et al* 1968).

Geology and topography

The soils studied were from three distinct geographical areas (figure 1), namely, the Callide Valley, the Dawson Valley and the Pegunny area. The geology of the three areas differs (Malone 1964). The Callide Valley is mapped as Tertiary sedimentary material with undifferentiated alluvium in the valley floor, the Dawson Valley is mapped as undifferentiated alluvium; while the Pegunny area is Triassic sedimentary material.

Isbell (1962) stated that it appeared that the deep gilgaied soils are composed of surficial deep clay sediments of Upper Cainozoic age that often are entirely unrelated to the nature of any underlying hard rock or sediment. Wright (1968) agrees with Isbell in his comment that, because of widespread surficial deposits, bedrock lithology has exercised only broad control in the area under study. However, he claims the deposits are locally derived colluvium-alluvium, with the fine-textured materials principally derived from Mesozoic and Palaeozoic shaly rocks. Topography of the particular areas sampled is a gently undulating plain.

Vegetation

The vegetation of undisturbed sites is loosely referred to as brigalow scrub. The dominant species of the upper storey is brigalow (*Acacia harpophylla*) with differing amounts of belah (*Casuarina cristata*) and *Bauhinia carronii*. Wilga (*Geijera parviflora*) is a small tree or shrub common in the understorey; sandalwood (*Eremophila mitchellii*) is less common. The vegetation has been described in detail by Speck (1968).

III. SOIL MORPHOLOGY

Soil morphology and micro-relief have been described previously by Isbell (1962) and Sweeney (1968). In our studies, the principal profile forms (Northcote 1971) recognized were Ug 5·24 at 21 sites, Ug 5·25 at two sites, Ug 5·35 at two sites and Ug 5·22 at one site. This confirms Isbell's (1962) statement that grey or greyish brown soil colours are most common in these soils. Although soil profile morphology was basically similar among sites,

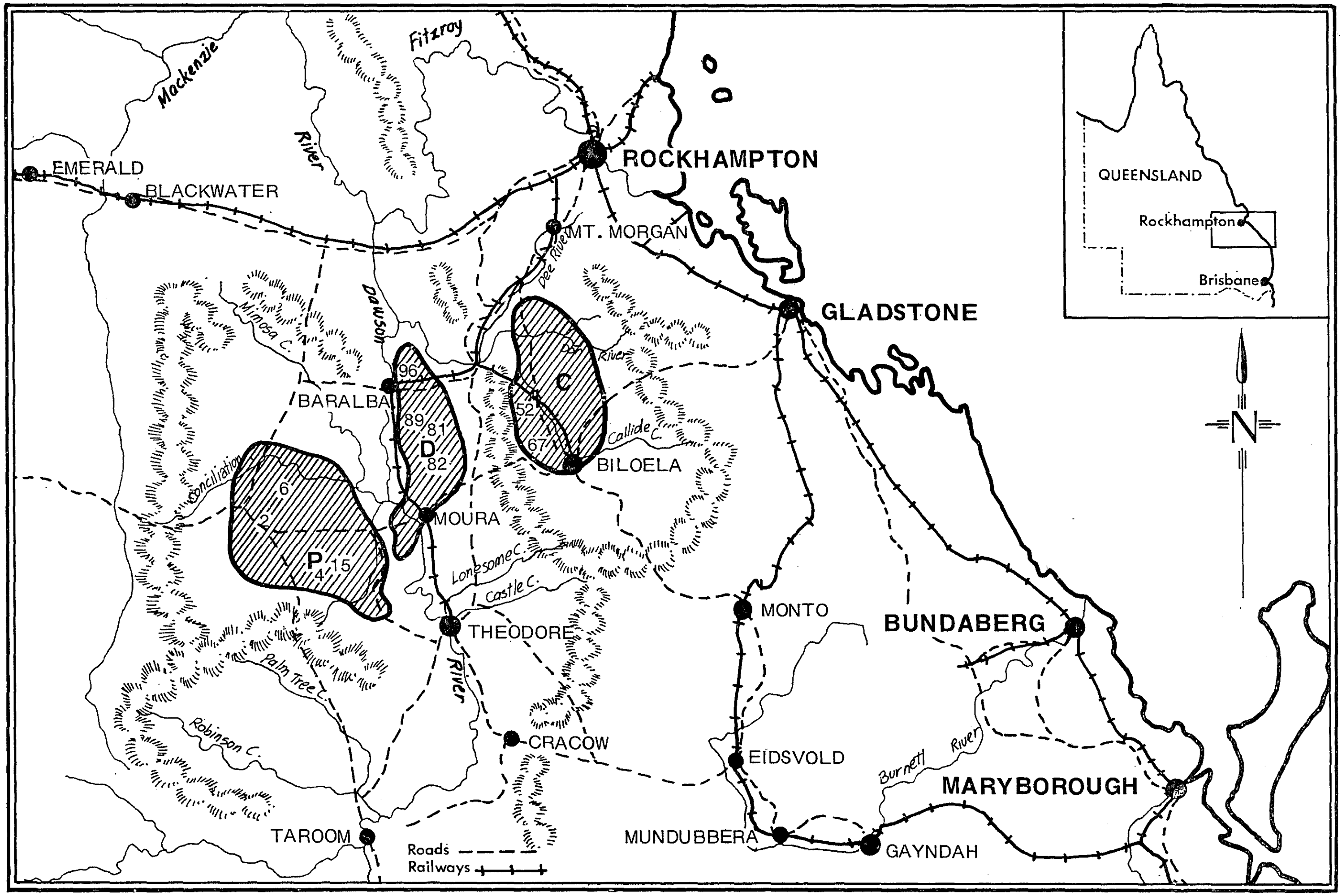

Figure 1.—Areas and site locations of soils used in chemical and nutrient studies in the Callide Valley (C), the Dawson Valley (D), and the Pengunny Area (P).

there were variations in surface soil texture from light clay to medium clay, and in structure from fine granular to fine blocky. Consistence and amount of organic litter also varied slightly among sites.

IV. SAMPLING PROCEDURES AND ANALYTICAL METHODS

A large number of surface samples (0 to 10, 10 to 20 cm) were taken from three areas for fertility assessment of the gilgaied clays. The numbers of sites in each area were 29 in the Callide valley, 30 in the Dawson valley and 39 in the Pegunny area.

The sites were virgin, cleared, or cultivated. Cleared sites were those which had been developed for pasture production but had not been cultivated for sucker control or crop production. Samples were taken from the gilgai mounds, or the area separating the depressions if mounds were not present. At each site, surface samples were taken from five positions oriented on a cross pattern with the central point being approximately 40 m from each of the other four. The soil from the same increment at all positions was bulked and subsequently subsampled.

For more detailed chemical assessment, soil profiles were sampled at seven sites in the Callide valley, eight in the Dawson valley and 11 in the Pegunny area. Samples were taken in 10 cm increments to 90 cm and thereafter in 20 cm increments to 150 cm. Surface samples had been taken at all these sites.

Electrical conductivity (E.C.), pH and chloride were measured on a 1 : 5 soil–water suspension at 25°C. Following washing with 90% ethyl alcohol, exchangeable cations were extracted by N ammonium chloride at pH 7·0 for samples with pH $< 7 \cdot 5$, and with alcoholic ammonium chloride buffered to pH 8·5 (Tucker 1954) for samples with pH $> 7 \cdot 5$. After destruction of alcohol in the leachate and addition of strontium chloride, exchangeable cations were measured using a Techtron AA4 atomic absorption spectrophotometer. Cation exchange capacity (C.E.C.) was obtained by determination of exchanged ammonium from the ammonium–saturated sample after removal of free ammonium chloride.

Total nitrogen was determined on a Kjeldahl digest and organic carbon by the Walkley–Black method (Piper 1950). Phosphorus was extracted with 0·01N sulphuric acid (Kerr and Von Stieglitz 1938), and also with 0·5M sodium bicarbonate (Colwell 1963). It was measured colorimetrically by the method of Murphy and Riley (1962).

V. DATA TREATMENT

Analytical data for soil profiles and surface samples were subjected to analyses of variance to detect differences in soil properties between four groups of soils representing Callide, Dawson, and two Pegunny groups—acid and alkaline subsoils respectively. Differences between soils in virgin, cleared and cultivated sites were also examined.

VI. CHEMICAL PROPERTIES OF THE SOIL PROFILE

For the various attributes, mean values at each horizon for all soils, together with the 95% confidence limits of the means were used to plot profile trends (figure 2). For pH, means are given for both acid and alkaline trend groups. Data for the larger number of composite surface samples are dealt with separately (table 3).

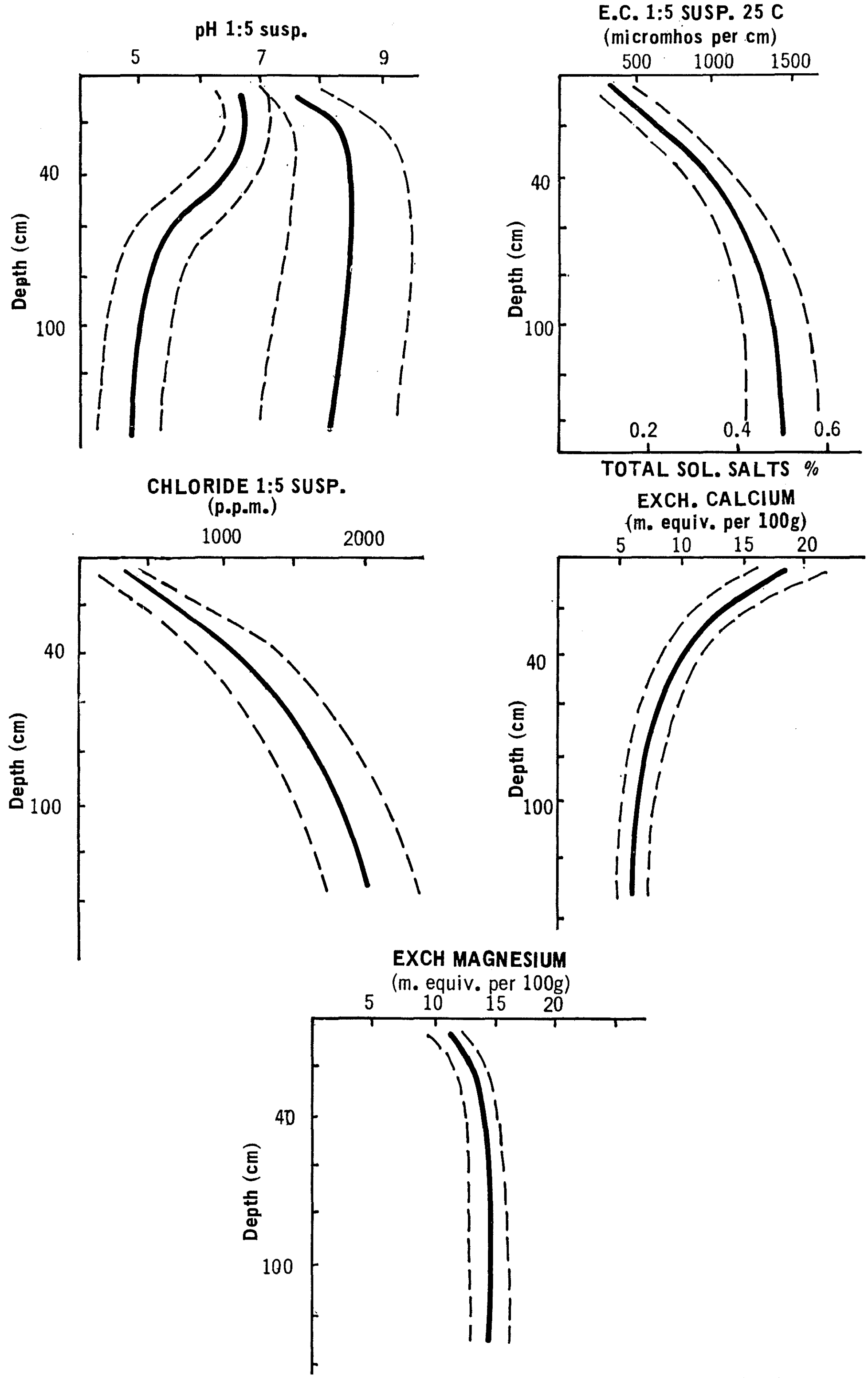

Figure 2.—Profile trends for selected chemical and physical properties showing mean values and 95% confidence limits of the mean.

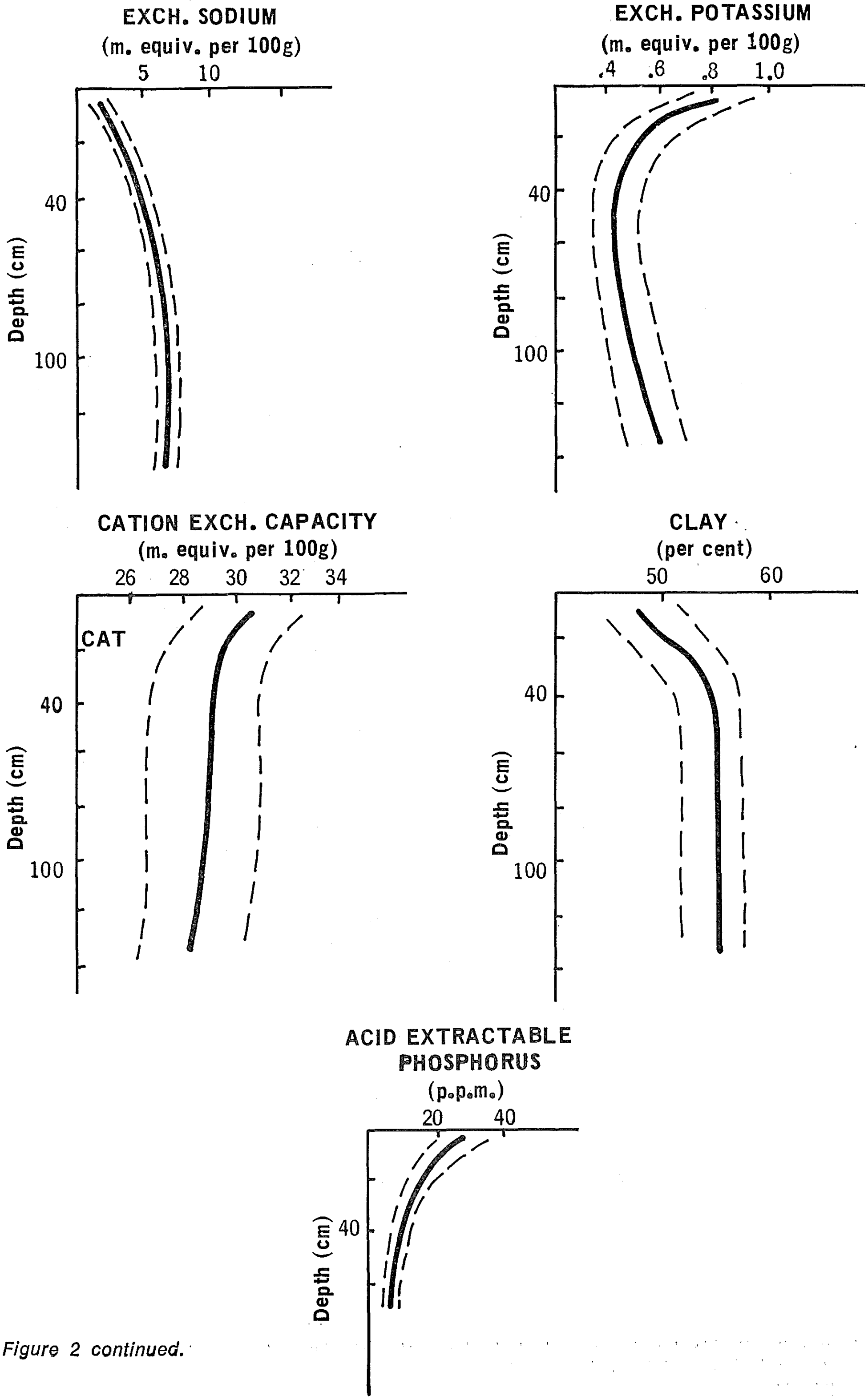

Figure 2 continued.

Analysis of variance between groups at each profile depth showed few significant differences between groups for available phosphorus, exchangeable sodium, exchangeable magnesium, exchangeable potassium, cation exchange capacity (C.E.C.) and electrical conductivity. For these attributes, only the mean profile is presented (figure 2). For other attributes including clay content, C.E.C. per 100 g of clay, exchangeable calcium, chloride and pH there are significant differences for some horizons between means of different groups. For these attributes data for selected horizons are presented in table 1 in addition to the mean profile trends in figure 2.

CLAY. The mean clay profile shows a small increase to about 40 cm, below which it remains constant at 55%. Clay content of Callide samples is significantly greater ($P < 0 \cdot 05$) than that of Dawson and alkaline Pegunny samples of each horizon shown in table 1 and also greater than acid Pegunny samples at 20 to 30 cm and 50 to 60 cm depths.

PHOSPHORUS. The mean acid extractable phosphorus profile shows a marked decrease to 20 cm, below which it remains reasonably constant about 8 p.p.m. Below 0 to 10 cm there were no significant differences between groups.

pH. The alkaline Pegunny group shows an increase in pH to 30 cm and values then remain about 8·5 to 150 cm. The mean acid trend profile for Callide, Dawson, and acid Pegunny groups (acid trend profiles) shows pH decreasing sharply with depth to 5·5 at 60 to 70 cm and then more gradually to 4·9 at 150 cm.

The alkaline Pegunny samples (alkaline trend profiles) show significantly higher pH ($P < 0 \cdot 01$) than acid Pegunny and Callide samples for all horizons and also higher pH than Dawson samples below 60 cm. In upper horizons Dawson samples show higher pH ($P < 0 \cdot 05$) than Callide and acid Pegunny samples.

CATION EXCHANGE CAPACITY. The mean C.E.C. profile shows little change below 30 cm (29 m. equiv. 100 g^{-1}) and there are no important differences between areas. Profile trends for all groups were similar. The sum of the exchangeable basic metal cations was close to C.E.C. for all horizons. This high base saturation occurred even in the strongly acid horizons.

Below 20 cm C.E.C. per 100 g of clay for Callide soils is significantly lower than for all other groups. Below 60 cm, C.E.C. per 100 g of clay is higher for alkaline Pegunny than for acid Pegunny samples.

EXCHANGEABLE CATIONS. For all profiles, including alkaline Pegunny, the mean profile trend shows a marked decrease in calcium down the profile. This decrease is sharp to about 50 cm and gradual below that depth. Below 30 cm there is no significant difference in exchangeable calcium between acid and alkaline Pegunny soils. However, Callide samples show significantly lower exchangeable calcium ($P < 0 \cdot 05$) than alkaline Pegunny or Dawson throughout the profile. The calcium saturation trend is similar to that of exhangeable calcium.

The mean profile trend for exchangeable magnesium shows a marked increase to 30 cm by which depth it is dominant. There is little change below this depth and magnesium accounts for approximately 50% of the C.E.C. throughout the remainder of the profile. There are no important differences between areas.

Exchangeable sodium values increase markedly with depth to about 50 cm. Below this depth, values increase only slightly and the mean value at 50 cm is about 90% of the mean profile maximum. Apart from the surface horizons, the confidence limits for the mean values do not differ greatly for the various horizons. The trend for exchangeable sodium as a percentage of cation exchange capacity (E.S.P.) is similar to that shown for exchangeable sodium. A mean E.S.P. of 15% (± 0·9) occurs about 30 cm and values of 20% are constant below 50 cm. There are no important differences between areas.

Below surface horizons, exchangeable potassium shows little change with depth, having a mean value about 0·5 m equiv. per 100 g throughout with no significant differences between different areas.

SALINITY. The salinity profile as indicated by electrical conductivity (E.C.) shows a trend similar to that of sodium but the change of slope occurs at a slightly greater depth (about 70 cm). The mean value for conductivity at 70 cm is about 90% of the mean profile maximum. There are no major differences between areas although there is evidence of higher E.C. values in Callide profiles in upper horizons.

TABLE 1

MEANS FOR SIX ATTRIBUTES OF SELECTED PROFILE INCREMENTS OF GILGAIED CLAYS IN THE CALLIDE AND DAWSON VALLEYS AND THE PEGUNNY AREA

Attributes	Increment (cm)	Pegunny* Mean Values		Callide	Dawson	Necessary Difference for Significance†	
		Alkaline	Acid			P < ·05	P < ·01
No. of sites		5	6	7	8		
pH	0–10	7·6	6·6	6·5	7·4	·9	1·3
	20–30	8·5	6·0	6·6	7·8	1·3	1·7
	50–60	8·5	5·2	5·3	6·7	1·3	1·8
	80–90	8·4	4·7	5·2	5·7	1·3	1·8
Chloride (p.p.m.)	0–10	82	183	640	180	418	569
	20–30	360	660	1 288	490	468	637
	50–60	916	1 475	1 780	1 186	709	965
	80–90	1 228	1 875	2 000	1 446	831	1 131
Clay (%)	0–10	44	46	53	45	9	12
	20–30	47	49	58	48	9	12
	50–60	49	54	62	52	8	11
	80–90	49	56	60	52	8	11
Exchangeable Calcium (m. equiv. per 100 g)	0–10	23	15	17	18	6·5	8·8
	20–30	15	10	9	14	4·7	6·4
	50–60	10	7·1	5·3	10	4·5	6·2
	80–90	9	5·8	3·9	8·6	3·6	4·9
Exchangeable Calcium/C.E.C. (%)	0–10	65	53	53	60	16·2	22·0
	20–30	51	36	34	46	14·7	20·0
	50–60	35	25	20	36	14·3	19·4
	80–90	30	20	15	29	11·4	15·4
Clay C.E.C. (m. equiv. per 100 g clay)	0–10	75	65	61	68	14·5	19·7
	20–30	65	60	45	64	12·7	17·2
	50–60	62	51	41	59	9·6	13·0
	80–90	62	51	42	58	9·7	13·1

* Pegunny divided into alkaline and acid groups.

† Necessary differences are those for smallest number of sites, that is, the highest necessary difference for significance.

For chloride, 90% of the mean profile maximum occurs in the 110 to 130 cm zone compared with 70 cm for E.C. Callide profiles have significantly higher chloride content in upper horizons than profiles from the other groups (table 1). The differences between areas in chloride content in the 30 to 60 cm zone are not reflected in different electrical conductivity values. This tends to indicate that where chloride differences occur, other soluble salts are also contributing to salinity. However analyses of water extracts (1 : 1 soil : water) for profile samples indicate that sodium and chloride are the dominant ions responsible for the salinity in all horizons (Webb, unpublished data). Sulphate (inferred from the differences between cation and anion concentration) is prominent in a few sites and gypsum was observed in some soil profiles.

VII. CHEMICAL PROPERTIES OF THE SURFACE SOIL

For the larger number of surface samples, total nitrogen, exchangeable calcium, exchangeable magnesium, exchangeable sodium and C.E.C. did not show significant differences between areas. Table 2 shows means of these attributes across all sites for 0 to 10 cm and 10 to 20 cm horizons.

TABLE 2

Mean Values and Coefficients of Variability (C.V.) of a Number of Attributes for Surface Soil (0 to 10, 10 to 20 cm) of the Gilgaied Clays in the Dawson and Callide Valleys and the Pegunny Area.

Attribute	No. of Sites	0 to 10 cm		10 to 20 cm	
		Mean	% C.V.	Mean	% C.V.
Total nitrogen (%)	34	0·137	18	0 094	21
Exchangeable cations (m. equiv. per 100 g)					
Calcium	34	21	34	20	42
Magnesium	34	11	26	13	25
Sodium	34	1·5	41	2 9	35
C.E.C. (m. equiv. per 100 g)	34	28	8	29	11

There were significant differences between areas in the 0 to 10 cm depth for acid extractable phosphorus, pH, exchangeable potassium, organic carbon, chloride and clay. In table 3, mean values are presented for these attributes for each area. They have been subdivided into virgin, cleared and cultivated sites.

Callide Valley sites are generally higher than Pegunny and Dawson sites in chloride, available phosphorus, organic carbon and clay content, but lower in pH. Similar differences occur for pH, exchangeable potassium, chloride and clay for 10 to 20 cm depth but data have not been presented.

TABLE 3

MEAN VALUES AND COEFFICIENT OF VARIABILITY (C.V.) FOR A NUMBER OF ATTRIBUTES FOR SURFACE SOIL (0 TO 10 CM) OF THE GILGAIED CLAYS IN VIRGIN (V) CLEARED (CL) AND CULTIVATED (CU) SITES IN THE PEGUNNY AREA, THE CALLIDE VALLEY AND THE DAWSON VALLEY.

Attribute		Pegunny			Callide			Dawson		
		No.	Mean	%C.V.	No.	Mean	%C.V.	No.	Mean	%C.V.
pH	V	10	7·5	6	7	6·1	12	7	6·9	6
	Cl	23	7·4	9	11	7·0	10	15	7·5	7
	Cu	6	7·6	10	11	6·9	10	8	7·5	6
Acid Extractable Phosphorus (p.p.m.)	V	10	19	52	7	34	38	7	30	58
	Cl	23	23	43	11	42	37	15	31	28
	Cu	6	34	11	11	51	41	8	40	26
Exchangeable potassium (m. equiv. per 100 g)	V	10	0·60	29	7	0·54	38	7	0·59	63
	Cl	23	0·51	38	11	0·63	23	15	0·41	44
	Cu	6	0·76	44	11	0·52	33	8	0·46	34
Organic carbon (%) ..	V	10	1·91	20	7	2·56	16	7	2·13	32
	Cl	23	1·77	18	11	2·17	23	15	1·82	22
	Cu	6	2·23	19	11	1·87	17	8	1·94	17
Chloride (p.p.m.) ..	V	10	157	42	7	376	50	7	251	77
	Cl	23	153	50	11	410	79	15	173	75
	Cu	6	273	82	11	294	86	8	294	68
Clay (%)	V	3	49	6	4	60	12	4	46	9
	Cl	5	48	4	6	57	7	2	51	17
	Cu	3	40	9	3	47	11	4	51	9

Within each area there are significant differences in some soil attributes between virgin, cleared and cultivated sites. Cleared and cultivated sites of Callide and Dawson have higher pH than virgin sites. Pegunny and Callide cultivated sites have higher acid extractable phosphorus than cleared or virgin sites, and a similar effect (non-significant) occurs in the Dawson sites.

Virgin sites in the Callide have higher organic carbon than cleared or cultivated sites. Virgin and cleared sites of Pegunny and Callide have higher clay than cultivated sites. Although no differences occur between areas for total nitrogen and exchangeable sodium, virgin sites overall have significantly higher total nitrogen than cleared or cultivated sites, while cultivated sites have significantly higher exchangeable sodium than virgin or cleared sites (table 4).

TABLE 4

MEAN VALUES AND COEFFICIENTS OF VARIABILITY (C.V.) FOR TOTAL NITROGEN AND EXCHANGEABLE SODIUM FOR THE SURFACE (0 TO 10 CM) OF THE GILGAIED CLAYS IN THE PEGUNNY AREA, THE CALLIDE VALLEY AND THE DAWSON VALLEY.

Attribute	Virgin			Cleared			Cultivated		
	No.	Mean	%C.V.	No.	Mean	%C.V.	No.	Mean	%C.V.
Total nitrogen (%) ..	11	0·154	16	13	0·130	19	10	0·127	15
Exchangeable Sodium (m. equiv. per 100 g)	11	1·3	24	13	1·3	43	10	2·1	35

VIII. DISCUSSION

The gilgaied clays are saline, strongly sodic soils with some, particularly in the Callide Valley, being strongly saline—strongly sodic. Isbell (1962) drew attention to the high mean salt levels in the surface of the gilgaied clays and suggested that these might affect plant establishment and yield. Results reported in our studies support the data of Isbell (1962) and provide a more detailed evaluation of the salt status of the gilgaied clays in the region studied.

Russell, Moore and Coaldrake (1967) stated that, in the gilgaied soil they studied from southern Queensland, although salinity increased with depth, isopleths of salt concentrations tended to follow the surface configuration. When cleared, salts redistributed and levels became higher in the mounds. The data from our study do not indicate the same effect in the central Queensland area. However, variability from site to site is so great that separate site studies would probably be required so that changes could be monitored from the virgin state to the developed state.

The data show the saline and sodic nature of the subsoils to be a characteristic property. The depth at which close-to-maximum values are encountered is also seen to be characteristic for the gilgaied clays in this region. The profile trends for exchangeable cations and salinity are important features and from these trends other characteristics may be inferred. The relatively small change in exchangeable sodium and salinity below the 50 to 60 cm zone suggests that this marks the lower limit of effective water movement in these soils.

The acid subsoils of the gilgaied clays have been reported previously (Hubble and Isbell 1958, Isbell 1962, and Russell, Moore and Coaldrake 1967). Isbell (1962) commented that for the acid trend gilgaied clays there was usually no apparent change in other soil properties accompanying the pH change other than a disappearance of any visible carbonate. Our data tend to support this statement.

Exchangeable calcium levels and exchangeable calcium as a percentage of C.E.C. do decrease with depth but this occurs for both acid and alkaline trends. Russell, Moore and Coaldrake (1967) suggest that brigalow forests may be partially responsible for the accumulation of calcium in the surface soils resulting in a neutral soil overlying an acid soil. Most profiles studied show neutral surface soils overlying acid subsoils, although some Callide Valley sites are acid throughout while in the Pegunny area clays may be alkaline to a considerable depth (150 cm).

The Callide Valley soil profiles differ markedly from those in the other areas in soluble salts, exchangeable calcium, clay content, and C.E.C. per 100 g of clay. In the surface, the Callide Valley soils also differ in acid extractable phosphorus, organic carbon and pH. These data suggest that the gilgaied clay soils of the Callide Valley were derived from different parent materials and/or have been subjected to different processes in their formation.

The higher acid extractable phosphorus levels in the cultivated soils compared with cleared and virgin soils may be due to mineralization of organic phosphorus following development. None of the sites sampled had been fertilized.

The lower total nitrogen for cleared and cultivated sites compared with virgin sites indicates depletion of nitrogen reserves following development. The higher exchangeable sodium in the surface 0 to 10 cm of cultivated soils may result from clay of high sodium content being introduced from subsurface horizons during cultivation.

The pH of surface soil at cleared and cultivated sites of the Callide and Dawson valleys is higher than at virgin sites. This supports the information put forward by Russell, Moore and Coaldrake (1967) who noted an increase in pH following burning and suggested this was due to large amounts of calcium contained in the vegetation being returned to the soil surface. The various other differences in properties between the virgin, cleared and cultivated sites are not readily explained. The drastic effects on the soil during mechanical clearing, windrowing, burning and cultivation are likely to differ depending on the operators, the methods and the equipment used.

The data on chemical fertility of the gilgaied clays indicate that levels of exchangeable cations are adequate, while acid extractable phosphorus levels are extremely variable and range from deficient to adequate. As a result, individual site sampling would be required for recommendations of phosphorus fertilizer usage. A general statement on the phosphorus requirement of these soils cannot be made on the basis of the survey data.

The indication of some depletion of organic matter suggests the need for a closer study of the effects of development on soil fertility.

It is evident that, in order to characterize a soil group properly, sufficient samples need to be taken to allow an appreciation of attribute variability. In this study, it is seen that there are differences between areas for some profile attributes but the profile means values provide an overall characterization of major soil properties which should be taken into account when management practices are being formulated.

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