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# Studies on solodic soils under Acacia harpophylla-Eucalyptus cambageana forests in central Queensland
## 1. Chemical characteristics

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## Summary

The chemical properties of solodized solonetz and solodic soils at 52 sites under *Acacia harpophylla* (brigalow)-*Eucalyptus cambageana* (Dawson gum) forests in central Queensland are described.

Analytical data for four groups of soil, based on thickness of A horizon, demonstrate the relationship of thickness of A horizon to many soil properties. Soluble salts, pH, exchangeable cations and clay content are higher throughout the profile for thin surfaced soils than for thick surfaced soils. All soils are sodic at depth and some are moderately saline. Chloride is the dominant anion in the subsoil. Acid extractable phosphorus, exchangeable potassium and extractable zinc values in the surface 0 to 10 cm are in the moderately low range and are variable. Bulk density of surface soils is relatively high (mean 1.32 g cm$^{-3}$). Callide Valley soils have higher acid extractable phosphorus and organic carbon values than similar soils in other parts of the region.

## 1. INTRODUCTION

In the Fitzroy River catchment of east-central Queensland deep solodized solonetz and solodic soils are important components of the Highworth, Thomby, Humboldt, Somerby and Blackwater land systems (Speck, Wright, Sweeney, Perry, Fitzpatrick, Nix, Gunn and Wilson 1968; Story, Galloway, Gunn and Fitzpatrick 1967; Gunn, Galloway, Pedley and Fitzpatrick 1967). Gunn (1967a,b) and Sweeney (1968) grouped the solidized solonetz and solodic soils of these land systems into several soil families on the basis of morphological attributes and reaction of the subsoil. Gunn (1967c) also described a soil catena which occurs in central Queensland and indicated that solodic and related soils supporting communities with *Acacia harpophylla* (brigalow) and *Eucalyptus cambageana* (bluckbutt or Dawson gum) occupied the lower slope situations of gently undulating lowlands. It is estimated that this land unit covers about 10 000 km$^2$ in the Fitzroy region (Gunn and Nix 1977).

The dominant land use on these soils has been grazing for beef production on sown pastures of buffel (*Cenchrus ciliaris*) and Rhodes grass (*Chloris gayana*), with limited cropping for cereals and cattle fattening. However, with the rapid expansion of cropping in central Queensland large areas of these solodic soils are now being developed for grain production, particularly in the eastern parts of the region. Gunn and Nix (1977) considered these lands to be best suited to grazing, and suitable only for occasional cropping because of severe limitations such as susceptibility to erosion, poor physical characteristics and moderate to severe salinity.

Gunn (1966) listed profile data for a few soils of Retro, Taurus and Wyseby families of the Isaac-Comet and the Nogoa-Belyando lands. Apart from the reports mentioned, there is very little published information on the chemical nature and fertility status of these solodic soils. Recently Graham, Webb and Waring (1981) presented information on the effects on soil nitrogen status of developing these soils for pasture and cropping. They noted that over a number of sites there was a general decrease in nitrogen and organic carbon in these solodic soils following development.

This paper describes the morphology and some chemical and physical properties of various solodized solonetz and solodic soils supporting communities of *A. harpophylla* and *E. cambageana* in east-central Queensland. Results of nutrient experiments in pots and an assessment of the fertility of the solodic soils will be reported separately.

## 2. ENVIRONMENT

### Climate

The climate of the area has been described by Fitzpatrick (1967a,b, 1968). Mean annual rainfall for the area studied ranges from 762 mm in the east to 610 mm in the west and shows high variability. The rainfall is seasonal with 70 to 75% of the average annual total falling in October to March.

Mean maximum temperatures range from about 21° to 22°C in the Biloela-Theodore and the Springsure-Emerald area for the June–July period. Mean minima range from 4.5° to 7°C. Maximum temperatures of 32° to 35°C occur in December and January. Heatwaves are common in the Emerald area with daily maximum temperatures over 38°C for 15 to 30% of the time in December and January. In the Biloela area, maximum temperatures greater than 38°C occur on an average of 3 days during both December and January. Minimum temperatures range from 18° to 21°C for this area.

Annual evaporation is high. Estimated mean annual tank evaporation (Fitzpatrick 1967a, 1968) for Springsure is 1175 mm and for Biloela 1562 mm. Highest rates of evaporation occur in October to January inclusive. Reduced evaporation in February is probably associated with slightly lower temperatures and more cloudiness.

Climate is a major factor controlling patterns of land use and the potential agricultural and pastoral productivity within the Fitzroy Region (Fitzpatrick 1965). The most important way in which climate controls production is through its effect on the available soil water.

### Geology and topography

The solodic soils studied are derived from a wide range of parent materials including the lower zones of denuded weathering profiles of Tertiary sediments. In the Callide Valley and the Comet area, they are derived from Tertiary sediments while in the Pegunny area west of the Dawson Range they are formed on Triassic sediments of the Moolayember formation. These are not as intensely weathered as the Tertiary sediments. In the Dawson Valley the soils are formed on undifferentiated alluvium which is probably derived from transported Tertiary clay. South west of Capella the soils are formed on undifferentiated alluvium and on the Permian Back Creek sediments, some of which are marine. They occur on broad crests and slopes of gently undulating to undulating terrain (Gunn 1967a,b; Sweeney 1968).

### Vegetation

Vegetation of undisturbed sites is characterized by *A. harpophylla* open forest, with emergent *E. cambageana* and a shrub layer comprising *Geijera parviflora* (in southern occurrences), *Eremophila mitchellii* and a low shrub layer of *Carissa ovata* (currant bush). The vegetation of the land systems in which the soils occur has been described by Pedley (1967), Story (1967) and Speck (1968).

## 3. METHODS

### Soil sampling

Soil profiles were described and sampled at 52 sites in central Queensland as shown in Figure 1. Criteria used to select sites were:

1. Soil profile form was duplex (Northcote 1971).
2. Site vegetation dominated by *A. harpophylla* and *E. cambageana*.
3. Site fell within one of the following land systems: Highworth, Thomby, Humboldt, Somerby or Blackwater.

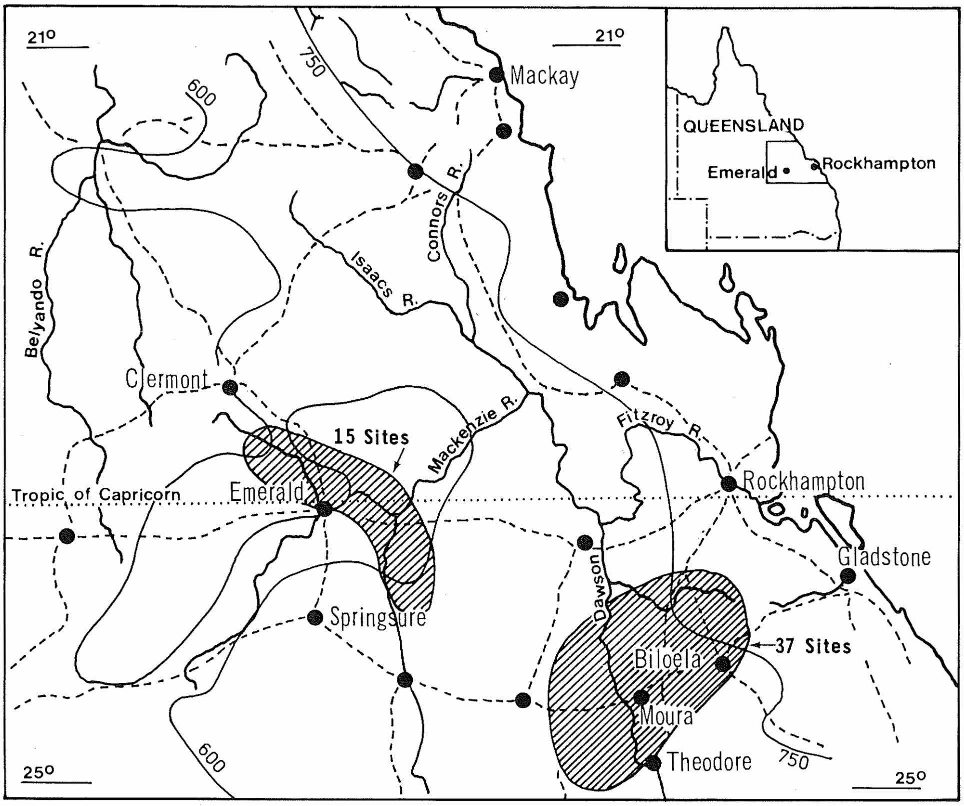

Figure 1. Site location of soils sampled in the survey.

Forty five sites were in virgin or relatively undisturbed condition; seven of the sites had been cleared and sown to pasture.

Each site was a visually uniform area of 100 $m^2$. At most sites the soil profile was examined and sampled from a 10 cm diameter core, taken with a rotary drill mounted on a four wheel drive vehicle. Profiles were classified after Northcote (1971). Morphological data were collected and coded after Walker, Ross and Beeston (1973).

The surface sample was a bulk of the profile surface plus nine other samples within a radius of 5 m from the profile.

Profile samples were taken in 10 cm increments except where obvious changes occurred, in which case the sample was split into two. Samples retained for analysis were generally 0 to 10, 10 to 20, 20 to 30, 50 to 60, 80 to 90 cm. Where parent material occurred before 90 cm, the last sample was usually analysed. At 6 sites deep samples were taken to 150 cm.

### Soil analysis

Electrical conductivity (EC), pH and chloride were measured on a 1:5 soil water suspension at 25°C. EC, pH, chloride, bicarbonate, sulphate, calcium, magnesium and sodium were measured also on 1:1 soil:water extracts from a selected number of soil profiles. Chloride was determined by potentiometric titration with 0.028 M $AgNO_3$ after the method of Stout and Johnson (1965).

Soil water extracts of 1:1 were obtained by centrifuge after shaking 1 h, standing overnight and reshaking 10 min before centrifugation. Bicarbonate was determined by titration with 0.01 M $HNO_3$ to pH 4.5 (Bower and Wilcox 1965). Chloride was determined as before. Calcium and magnesium were determined by atomic absorption and sodium by flame emission.

Sulphate was determined turbidimetrically in a hydrochloric acid medium using barium chloride (APHA 1975).

Exchangeable cations were extracted with alcoholic ammonium chloride adjusted to pH 8.5 (Tucker 1954). 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 (CEC) was obtained by determination of exchanged ammonium from the ammonium saturated samples remaining after the leaching for exchangeable cations. Total nitrogen was determined on a Kjeldahl digest, and organic carbon by the Walkey-Black method (Piper 1950). Phosphorus was extracted with 0.005 M sulphuric acid (Kerr and von Stieglitz 1938), and measured colorimetrically by the method of Murphy and Riley (1962). Copper and zinc were determined by atomic absorption spectrophotometry after extraction with DTPA (Follett and Lindsay 1971) while total phosphorus, sulphur and potassium were determined by x-ray fluorescence spectroscopy.

Particle size distribution was determined by the pipette method of Day (1965) after dispersion with cation exchange resin after Edwards and Bremner (1965) with overnight end over end shaking. There was no pretreatment of the sample. Moisture content at $-1/3$ and $-15$ bars was determined on ground samples equilibrated on a ceramic plate (McIntyre 1974). Bulk densities were determined on samples taken with a 5 cm diameter steel tube. Extractable copper and zinc, total phosphorus, sulphur and potassium, particle size and moisture content are reported on an oven dry basis. All other determinations are on an air dry basis.

### Data analysis

Soil profile data are presented as mean profile trends, while differences between soil groups in surface data were compared using analysis of variance.

## 4. SOIL MORPHOLOGY

All soils selected in our study had morphological features of solodic and solodized solonetz soils (Stace, Hubble, Brewer, Northcote, Sleeman, Mulcahy and Hallsworth 1968). There were 15 Dy*, 11 Dd, 24 Db and 2 Dr soils (Northcote 1971). The three most common subdivisions generally occurred in different positions in the landscape. The Dy and Db soils usually occurred on mid and upper slope situations in gently undulating to undulating lands. The Dd soils generally occurred in lower situations and were occasionally associated with clay soils.

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*Dy, Dd, Db and Dr are subdivisions of the primary profile form.

To assess the chemical status of the soils two methods of grouping were used. Initially, soils were grouped on the basis of subdivisions of primary profile forms into Dy, Db and Dd soils. However, because of profile variability within each group, particularly in A horizon thickness, soils were classified into four groups based on thickness of A horizons.

Group 1 with 7 sites had A horizons up to 10 cm thick, Group 2 with 19 sites had A horizons 11 to 20 cm thick, Group 3 with 18 sites had A horizons 21 to 30 cm thick, and Group 4 with 8 sites had A horizons 31 to 53 cm thick.

Sites in the four groups showed a relationship between position on slope and the thickness of the A horizon. Sites in Group 1 occurred mainly in lower and mid slope positions, those in Groups 2 and 3 occurred mainly in mid slope positions, and those in Group 4 occurred in mid and upper slope positions.

Gunn (personal communication) described 62 sites with brigalow-Dawson gum communities during resource surveys in central Queensland (Gunn *et al.* 1967; Story *et al.* 1967). When these data are compared to those of this current study a similar proportion (67%) of the sites had A horizons 11 to 30 cm thick.

All surface horizons were hard setting when dry, usually massive, and brown to very dark greyish brown. Of the 52 soils examined 41 had a thin (< 5 cm) bleached $A_2$ horizon. Most of the Dy and Db soils and some of the Dd soils exhibited columnar or degraded columnar structure in the B horizon. Calcium carbonate concretions occurred in most soils in the 40 to 80 cm zone. Very small manganiferous concretions were common in the upper 30 cm of most soils.

## 5. CHEMICAL AND PHYSICAL PROPERTIES

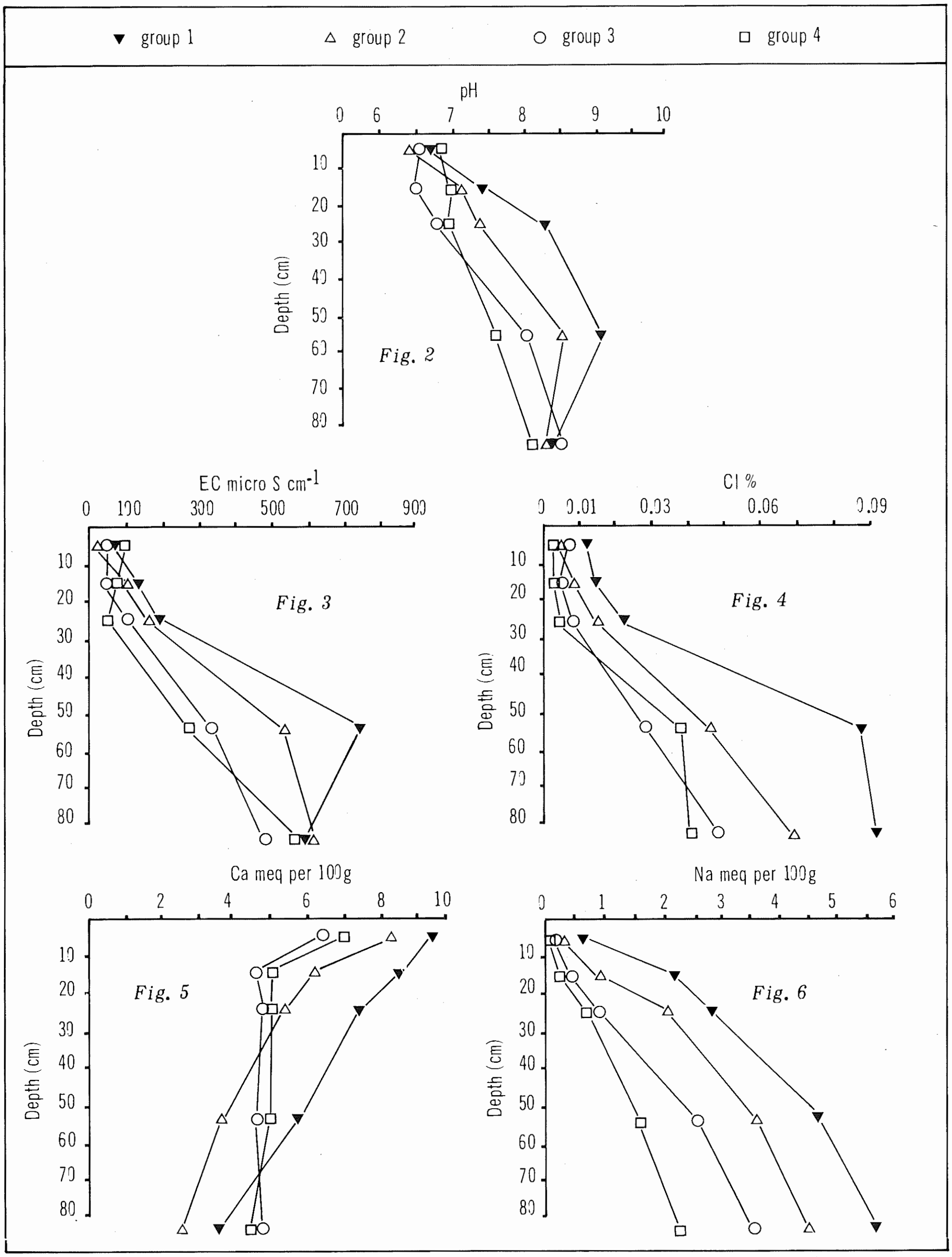
### Soil profiles

Mean values of chemical properties and clay contents of the four soil groups are shown in Figures 2 to 15. Profile values for all soil properties generally reflected the differences between the thickness of A horizons for the four groups. For many of the soil properties, the thinnest surface group had higher values than the other groups throughout the profile.

**pH.** Profile trends for pH (Figure 2) showed an increase with depth for each soil group. The two thinner surfaced groups reached a maximum about the 50 to 60 cm zone while the other two groups were still increasing in the 80 to 90 cm zone. In a few cases, pH was determined on soils to 150 cm. Generally, the soils became acid (pH 5.2) although some were neutral (pH 7.0). The occurrence of very acid clay at depth is similar to findings reported for the gilgaied clays (Hubble and Isbell 1958; Isbell 1962; Webb, Crack and Gill 1977). It is unlikely that the reaction at these depths of 120 to 150 cm would affect the growth of pastures or crops.

**Soluble salts.** Profile trends for electrical conductivity (EC) (Figure 3) and chloride (Figure 4) generally showed an increase with depth. Group 1 soils showed an accumulation of chloride and EC at 50 to 60 cm. Group 4 soils showed no increase in chloride below 50 to 60, while EC increased to 80 to 90 cm. This is probably due to the presence of gypsum (based on $SO_4$ analyses) in the 80 to 90 cm zone in six of the eight profiles analysed in Group 4. This is supported further by total S values for the same group of soils (Figure 15).

The chloride and EC values for the 1:1 extracts of the selected profiles showed very similar trends to the 1:5 suspensions. For the 50 to 60 and 80 to 90 cm samples chloride was the dominant anion. For the four soil groups, the EC chloride correlations for 50 to 60 and 80 to 90 cm zones were very high (Table 1).



Figures 2–6. Profile trends for selected chemical properties of solodized-solonetz and solodic soils in four groups based on thickness of A horizon. Group 1 0 to 10 cm, Group 2 11 to 20 cm, Group 3 21 to 30 cm; Group 4>30 cm.

**Table 1.** **Correlation coefficients (*r*) for chloride and electrical conductivity of 1:1 soil:water extracts for 50 to 60 cm and 80 to 90 cm zones of four soil groups**

| Soil groups | 50–60 cm zone | 80–90 cm zone |
|---|---|---|
| | *r* | *r* |
| 1 | 0.99 | 0.93 |
| 2 | 0.95 | 0.91 |
| 3 | 0.97 | 0.97 |
| 4 | 0.99 | 0.99 |

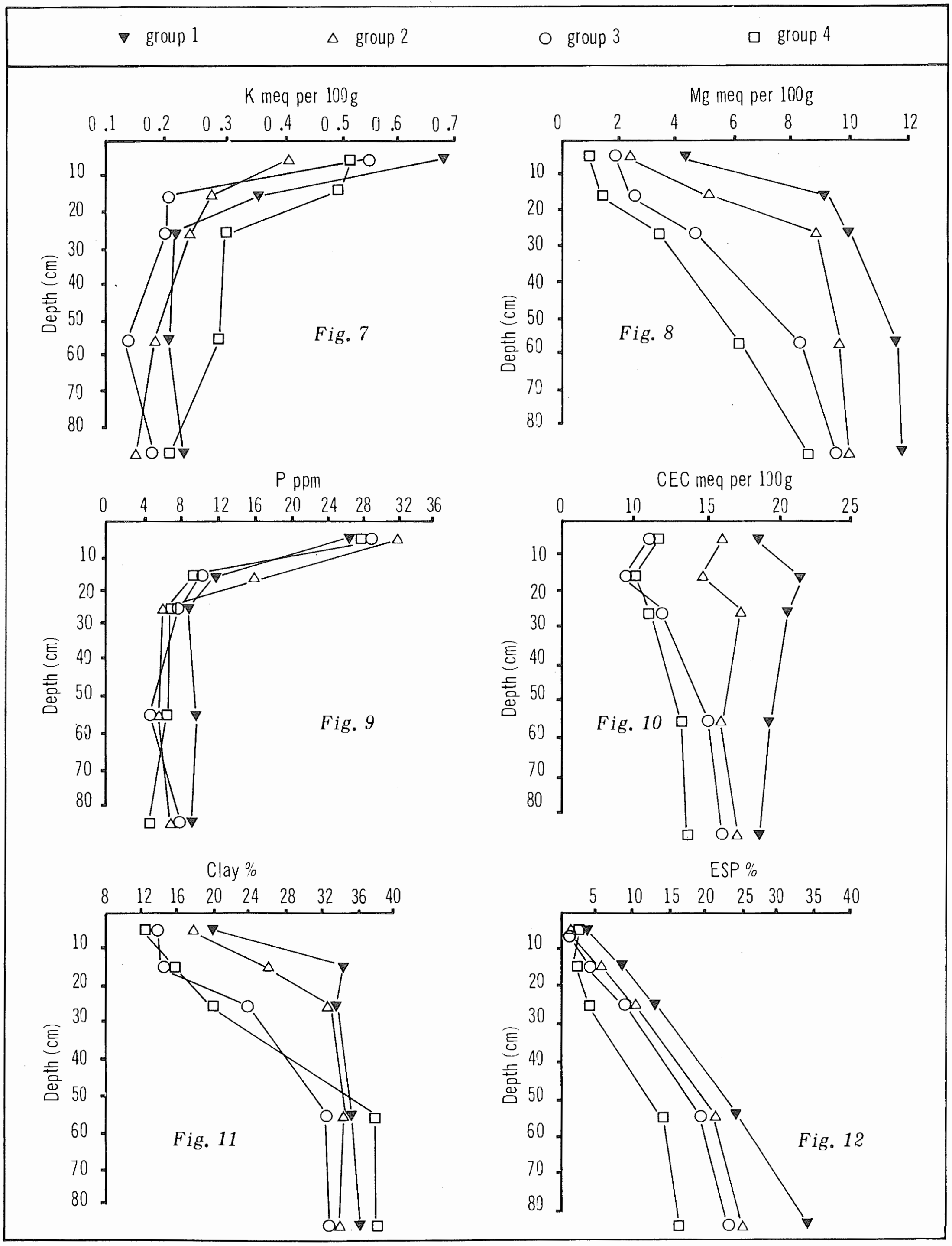
The accumulation zone shown by chloride and electrical conductivity in the 50 to 60 cm zone of the thinnest A horizon group indicates that the average moisture penetration is not past this zone. Soils of Groups 2 and 3 showed a steady increase in chloride down the profile and there is little or no indication of a zone of accumulation, although there are slight inflexions in EC values at about 60 cm. This may indicate that the parent materials are inherently salt-affected and that the chloride may have been removed from the upper horizons. Using criteria of Northcote and Skene (1972) the soils are non-saline. The higher levels of salinity at depth in the thinner surfaced soils could restrict rooting depth and moisture usage by salt sensitive plants.

**Exchangeable cations and CEC.** Profile trends for exchangeable calcium (Figure 5) and magnesium (Figure 8) varied among the four soil groups. Mean exchangeable calcium profile values showed that the two thinner surfaced groups had decreasing values down to 80 to 90 cm while the thicker surfaced groups had decreased to the 10 to 20 cm zone, then changed little to 80 to 90 cm. This trend appeared to be unrelated in pH, clay or CEC. Mean profile values for exchangeable magnesium of the soil groups were related to the thickness of the A horizon.

Exchangeable magnesium values of the two thinner surfaced groups increased to 20 to 30 cm and then varied little down to 80 to 90 cm. However, the other groups showed increased values to 80 to 90 cm. All groups had high values in the 80 to 90 cm zone. Exchangeable potassium (Figure 7) trends were similar for all groups with mean values decreasing markedly from the surface to 20 to 30 cm and then changing only slightly below that zone.

All groups had similar trends for exchangeable sodium (Figure 6) and the mean profile values were strongly related to the thickness of the A horizon. Mean values increased with depth to 80 to 90 cm where the thinnest and thickest surfaced groups differed markedly. Exchangeable sodium percentage (ESP) (Figure 12) increased with depth for each soil group. Trends differed slightly at depth. Group 1 soils showed a steady increase in ESP to the 80 to 90 cm zone. In Groups 2, 3 and 4 the rate of increase was less in the deepest zone. All soils had ESP values in the B horizon exceeding 15, which is regarded as characteristic of strongly sodic soils (Northcote and Skene 1972). Again, below the 0 to 10 cm zone mean, profile values were related to the thickness of the A horizon.

The trends for exchangeable magnesium indicated that maximum or near maximum values occurred in the upper B horizon for Groups 1 and 2, while values were still increasing markedly with depth in Groups 3 and 4. This is slightly different from the trend for exchangeable sodium, where a gradual increase still occurred at depth in all soil groups. The exchangeable calcium trend was opposite to the exchangeable sodium trend for Groups 1 and 2, and opposite to the exchangeable magnesium trend for all groups.



Figures 7–12. Profile trends for selected chemical properties of solodized-solonetz and solodic soils in four groups based on thickness of A horizon. Group 1 0 to 10 cm, Group 2 11 to 20 cm, Group 3 21 to 30 cm, Group 4>30 cm.

Mean CEC profiles (Figure 10) showed some differences in profile trends. The 10 to 20 cm zone values for Groups 2, 3 and 4 showed a definite decrease in the A horizon below the surface 0 to 10 cm. This probably reflects the lower levels of organic matter in the 10 to 20 cm zone as there were no comparable decreases in clay percentages. Group 1 soils did not show a similar decrease because the 10 to 20 cm zone was in the upper B horizon with a higher clay content. Differences in mean profile values reflected differences in thickness of the A horizon.

**Phosphorus.** Mean values for acid extractable phosphorus (Figure 9) for the four groups showed a similar trend over depth. There was a very marked decrease below the surface 0 to 10 cm to very low values at depth. The decrease in extractable phosphorus below the surface may reflect accretion at the surface by vegetation.

Profile trends for total phosphorus (Figure 13) were similar to those for acid extractable phosphorus. Mean profile values decreased markedly at depth.

**Potassium.** Mean profile trends for total potassium (Figure 14) showed differences between the soils of Group 4 and the soils of the other three groups. In Group 4, total potassium showed a slight increase with depth.

**Sulphur.** Trends for total sulphur (Figure 15) showed an accumulation zone in the 50 to 60 cm zone for Groups 1 and 2 and in the 80 to 90 cm zone for Group 4. Group 3 soils did not show an accumulation zone. Accumulation of total sulphur at depth may be associated with gypsum or soluble sulphate. Water extract analyses indicated that in a few profiles a sulphate bulge occurred in the 50 to 60 cm zone. As a result plant sulphur deficiency in those sites is unlikely.

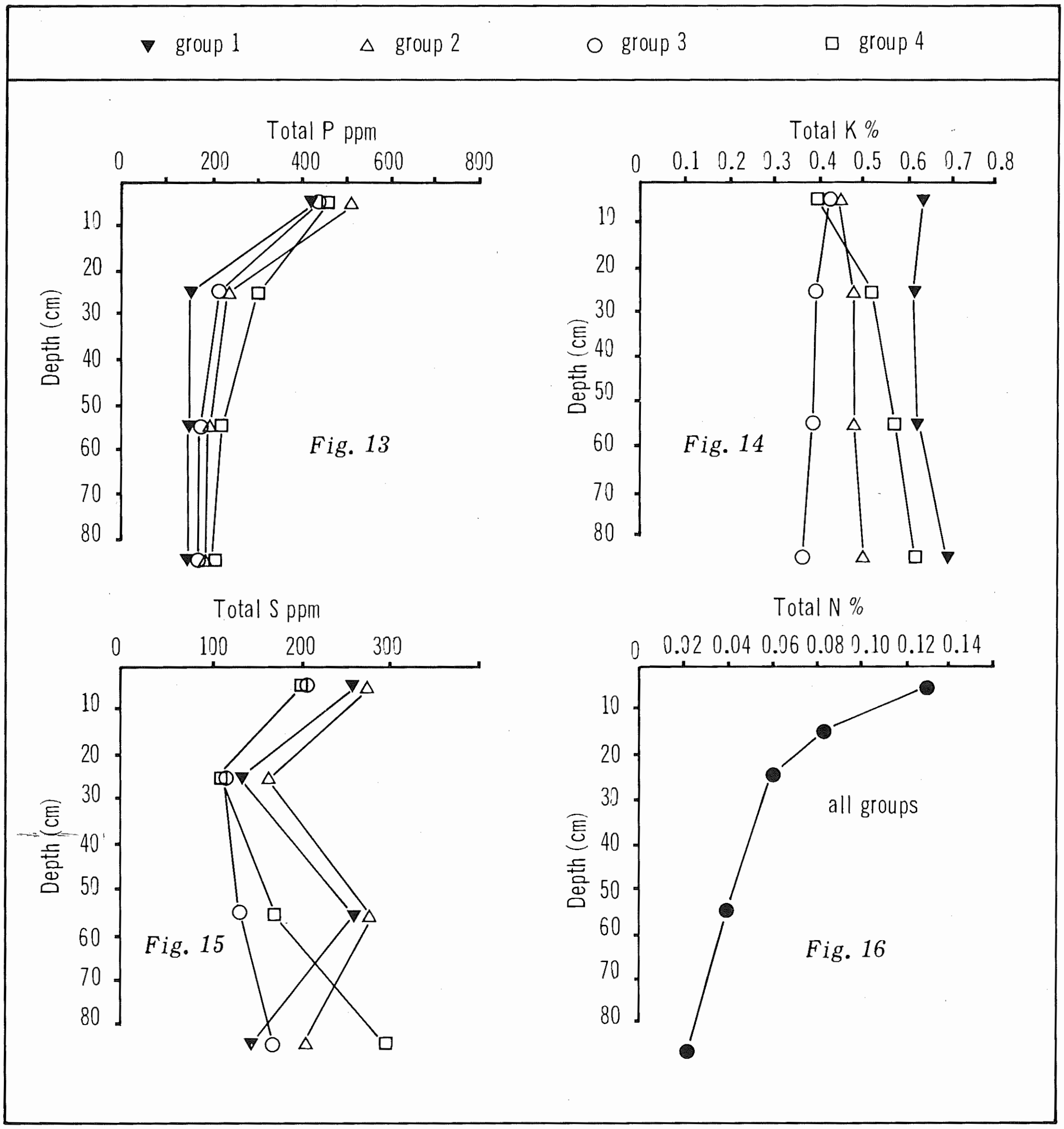
**Nitrogen.** Nitrogen profile trend (Figure 16) was very similar across 15 sites analysed and only the mean trend for all sites is presented. There is a very marked decrease in concentration with depth to extremely low values. A more detailed evaluation of the nitrogen status of solodic soils was carried out concurrently with this survey and was reported by Graham *et al.* (1981).

**Clay.** Mean clay content profiles (Figure 11) for the four groups showed an increase with depth for each group up to a maximum of about 35%. Once again groups were ordered in relation to thickness of A horizon in the upper part of the profile, but at depth Group 4 soils had the highest clay percentage.

**Clay activity ratio: (CEC/Clay content).** Clay activity ratio of the B horizons of all soil groups showed some variation with a few sites having very low values. However, there were no marked differences between the group means for the upper B and lower B horizons indicating that parent material of the soils is not related to the groups selected (data not presented).

**Bulk density.** Multiple sampling at 6 sites in the Callide Valley and Brigalow Research Station and from 2 sites near Emerald indicated very high bulk density in the B horizon. The surface bulk density varied but was typically 1.2 to 1.4 g $cm^{-3}$. Data from more sites are given in the section on surface soils. Below the surface, bulk density rose sharply to 1.6 to 1.8 g $cm^{-3}$ in the 10 to 50 cm zone, increasing even further in some sites to 1.9 and 2.0 g $cm^{-3}$.

The bulk density in the B horizons of these soils is probably limiting plant growth because of restriction to root penetration. Inspections of pits and large core holes revealed a concentration of root material above the B horizon. In similar soils near Emerald, Shaw (personal communication) found that after ponding water on the surface, moisture moved into the B horizon via cracks between structural units and spread laterally at lower depths.



Figures 13–16. Profile trends for selected chemical properties of solodized-solonetz and solodic soils in four groups based on thickness of A horizon. Group 1 0 to 10 cm, Group 2 11 to 20 cm, Group 3 21 to 30 cm, Group 4>30 cm.

**$-1/3$ and $-15$ bar moisture.** Mean gravimetric moisture contents at $-1/3$ and $-15$ bar water potentials of a number of soils of different A horizon thicknesses are presented in Table 2.

A regression analysis of $-1/3$ and $-15$ bar moisture with clay percentage across 25 sites and 4 depths (0 to 10, 20 to 30, 50 to 60, 80 to 90 cm) indicated that $-15$ bar moisture was more closely associated than $-1/3$ bar moisture ($r^2 = 0.76$). The equation was of the form

$$y = 3.38 + 0.289\,x$$

where $y$ is $-15$ bar moisture and $x$ is clay percentage.

In addition there was a close relationship between $-1/3$ bar and $-15$ bar moisture and the significant regression equation was

$$y = 3.34 + 1.573\,x \ (r^2 = 0.88,\ n = 97)$$

where $x$ is $-15$ bar moisture percentage and $y$ is $-1/3$ bar moisture percentage.

**Table 2. Mean gravimetric moisture percentages for $-1/3$ and $-15$ bar pressures for selected depths of soils with different thickness of A horizons**

| Soil depth (cm) | Group 1<br>A horizon 1-10 cm<br>$n = 5$ | | | | Group 2<br>A horizon 11-20 cm<br>$n = 10$ | | | | Group 3<br>A horizon 21-30 cm<br>$n = 6$ | | | | Group 4<br>A horizon > 30 cm<br>$n = 5$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture % | | | | Moisture % | | | | Moisture % | | | | Moisture % | | | |
| | $-1/3$ bar | | $-15$ bar | | $-1/3$ bar | | $-15$ bar | | $-1/3$ bar | | $-15$ bar | | $-1/3$ bar | | $-15$ bar | |
| | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. | $\bar{x}$ | s.e. |
| 0–10 | 16.3 | 2.1 | 9.2 | 2.4 | 17.3 | 1.1 | 9.1 | 0.7 | 13.3 | 1.7 | 6.5 | 0.9 | 15.1 | 1.0 | 7.3 | 0.7 |
| 20–30 | 23.1 | 3.6 | 12.0 | 2.3 | 21.5 | 1.4 | 12.8 | 0.7 | 12.4 | 1.1 | 5.6 | 0.7 | 14.0 | 2.7 | 7.1 | 1.6 |
| 50–60 | 26.4 | 1.4 | 13.7 | 1.1 | 26.2 | 0.9 | 13.6 | 0.6 | 22.5 | 1.2 | 11.8 | 1.0 | 25.5 | 2.7 | 14.0 | 1.5 |
| 80–90 | 28.5 | 1.7 | 14.6 | 1.2 | 26.3 | 1.5 | 12.9 | 1.3 | 24.9 | 1.7 | 12.8 | 0.9 | 24.8 | 3.8 | 13.6 | 2.1 |

Moisture at $-15$ bars was regressed on CEC for the surface and the B horizon (50 to 60 and 80 to 90 cm zones). The relationship with the B horizon was poor ($r^2 = 0.284$, $n = 49$) but with the surface was relatively good ($r^2 = 0.61$, $n = 25$).

## Surface soils

For the surface soils (0 to 10 cm) there were significant differences between the four groups of soil in exchangeable magnesium, exchangeable sodium, CEC, total nitrogen, clay content and air dry moisture. Mean values for a range of surface soil properties are shown in Table 3.

The thin surfaced soils of Group 1 had a higher ($P < 0.05$) exchangeable magnesium, exchangeable sodium and CEC than the other soils. Group 2 soils also had higher values ($P < 0.05$) than soils of Groups 3 and 4. Soils of Groups 1 and 2 had higher clay content than soils in Groups 3 and 4 ($P < 0.05$). Exchangeable potassium means for the surface were greater than 0.2 meq per 100 g which is widely accepted as a minimum for adequate plant growth (Williams and Lipsett 1960). However, variability is high and a few sites had values of 0.1 to 0.2 meq per 100 g soil. The two thick A horizon soil groups (3 and 4) had low total nitrogen values, which were significantly ($P < 0.05$) different from the moderate value for Group 2 soils.

Mean extractable phosphorus values for the surface of the four groups are in the moderately low range and are probably adequate for pastures and crops. However, the standard error associated with the mean demonstrates the high variability inherent in these soils and quite low values are common. The values for extractable zinc are also highly variable and at some sites this nutrient could be deficient for plant growth. Over all depths and all sites, acid extractable phosphorus was significantly correlated ($r = 0.61$, $P < 0.01$) with total phosphorus, and for the surface soils total phosphorus was significantly correlated ($r = 0.73$,

$P < 0.01$) with total nitrogen. Bulk density of surface soils from 30 virgin sites ranged from 1.15 to 1.53 g cm$^{-3}$ with a mean of 1.32. For a comparable number of developed sites the range was 1.29 to 1.66 g cm$^{-3}$ with a mean of 1.45.

**Table 3. Means and standard errors (s.e.) for properties of surface soil of four soil groups with different thickness of A horizon**

| Soil property | Group 1<br>$n = 7$<br>Mean | <br><br>s.e | Group 2<br>$n = 19$<br>Mean | <br><br>s.e | Group 3<br>$n = 18$<br>Mean | <br><br>s.e | Group 4<br>$n = 8$<br>Mean | <br><br>s.e |
|---|---|---|---|---|---|---|---|---|
| pH | 6.6 | 0.29 | 6.5 | 0.18 | 6.5 | 0.18 | 6.9 | 0.27 |
| Extractable phosphorus (ppm) | 27 | 9.0 | 32 | 5.5 | 29 | 5.6 | 28 | 8.5 |
| Exchangeable cations meq per 100 g | | | | | | | | |
| Ca | 9.2 | 1.2 | 8.4 | 0.7 | 6.5 | 0.8 | 7.0 | 1.1 |
| Mg | 4.2 | 0.4 | 2.4 | 0.2 | 2.0 | 0.3 | 0.9 | 0.4 |
| Na | 0.61 | 0.09 | 0.22 | 0.06 | 0.19 | 0.06 | 0.14 | 0.09 |
| K | 0.67 | 0.12 | 0.42 | 0.07 | 0.54 | 0.07 | 0.52 | 0.11 |
| Cation exchange capacity meq per 100 g | 18 | 1 | 16 | 1 | 11 | 1 | 12 | 1 |
| Chloride (%) | 0.012 | 0.002 | 0.004 | 0.002 | 0.005 | 0.002 | 0.003 | 0.002 |
| Total nitrogen (%) | 0.14 | 0.02 | 0.15 | 0.01 | 0.11 | 0.01 | 0.11 | 0.02 |
| Organic carbon (%) | 1.8 | 0.3 | 1.8 | 0.2 | 1.5 | 0.2 | 1.6 | 0.3 |
| Total phosphorus (ppm) | 431 | 65 | 510 | 40 | 440 | 42 | 456 | 57 |
| Total sulphur (ppm) | 256 | 36 | 274 | 23 | 209 | 23 | 210 | 32 |
| Total potassium (%) | 0.64 | 0.20 | 0.45 | 0.13 | 0.43 | 0.13 | 0.43 | 0.18 |
| Extractable copper (ppm) | 2.1 | 0.38 | 2.5 | 0.24 | 2.1 | 0.25 | 1.9 | 0.34 |
| Extractable zinc (ppm) | 0.9 | 0.35 | 1.3 | 0.22 | 0.9 | 0.23 | 0.6 | 0.31 |
| Clay (%) | 20 | 2 | 17 | 1 | 13 | 1 | 13 | 2 |
| Air dry moisture (%) | 3.14 | 0.004 | 2.46 | 0.002 | 1.93 | 0.002 | 1.81 | 0.001 |

Air dry moisture content (ADM) of 0 to 10 cm of Group 1 soils was significantly higher ($P < 0.05$) than for the other groups. Group 2 ADM was also significantly higher than Group 4 ADM ($P < 0.05$). This is probably a consequence of the higher clay and CEC values of the thinner surfaced soils. CEC and ADM also were significantly correlated ($r^2 = 0.7$, $n = 42$).

To compare the surface soil properties of the different parts of the region, site values from the Callide Valley, the Dawson Valley, the Pegunny area and the Comet-Capella area have been presented in Table 4. The Callide Valley sites had significantly higher ($P < 0.05$) acid extractable phosphorus and organic carbon values in the surface than the other sites. Total nitrogen was also higher but the differences were not significant. These differences indicate that soils in the Callide Valley may be derived from different parent material or were developed under different climatic conditions. Rainfall of the Callide Valley is slightly higher than in the

**Table 4. Mean acid extractable phosphorus, organic carbon and total nitrogen of surface soil (0 to 10 cm) of Callide, Dawson, Pegunny and Comet-Capella areas**

| Areas | Number of sites | Acid extractable P (ppm)<br>Mean | <br>s.e. | Organic C %<br>Mean | <br>s.e. | Total N %<br>Mean | <br>s.e. |
|---|---|---|---|---|---|---|---|
| Callide | 7 | 60 | 7.9 | 2.3 | 0.19 | 0.16 | 0.018 |
| Dawson | 7 | 20 | 7.9 | 1.7 | 0.19 | 0.13 | 0.018 |
| Pegunny | 24 | 26 | 4.2 | 1.5 | 0.11 | 0.11 | 0.014 |
| Comet-Capella | 12 | 26 | 6.0 | 1.7 | 0.15 | 0.14 | 0.014 |

other areas but density of vegetation was no different. Clay activity ratios (CEC/Clay) for the surface and subsurface of soils in the Callide Valley were not significantly different from those for the other areas, indicating that the clay mineralogy at least was similar.

## 6. GENERAL DISCUSSION

The profile and surface analytical data indicate that there are marked differences in soil properties among soils with varying thickness of A horizon. Some of these differences would almost certainly be reflected in pasture and crop growth. Analytical and morphological data suggest that thickness of A horizon is an important property controlling or at least influencing plant available water. Using the relationships developed by Shaw and Yule (1978), estimates of plant available water can be calculated using CEC and EC data or air dry moisture and −15 bar moisture contents with an estimate of rooting depth inferred from the chloride profile. They list (Table 22, p. 55) measured and predicted plant available water for four solodic soils from the Emerald area. Their data show that plant available water increases with thickness of A horizon. The various relationships between moisture contents, CEC and clay developed in this survey, while significant, are of little predictive value and correlation coefficients are not as high as those of Shaw and Yule (1978). There are a number of reasons for this, the main one being that the range of soils and consequent CEC and clay values encountered in our study were quite different. (For example, CEC 6 to 23 compared with 3 to 81 meq per 100 g of Shaw and Yule (1978).)

In general, the solodized solonetz and solodic soils examined in this study have higher fertility than the north Queensland solodics (Crack and Isbell 1970). They have considerably higher values in extractable phosphorus, total phosphorus, total sulphur, total nitrogen and organic carbon. This may be due partly to the large differences in vegetation growing on these soils. Brigalow is a legume and symbiotic nitrogen fixation may be responsible for some of the nitrogen accumulated in the surface of these soils. Opportunity for litter accumulation is probably higher in the central Queensland soils where plant density is higher and frequency of fire is lower.

The solodized solonetz and solodic soils have a few features in common with the gilgaied clays of the same area (Webb *et al.* 1977). Both groups of soils exhibit high exchangeable sodium percentages and occasionally high salt values at depth. In addition they both support major plant communities dominated by brigalow. The rapid decrease in extractable and total phosphorus with depth is another feature common to both groups of soils. Total nitrogen values for solodic soils with A horizon as deep as 20 cm were similar to those for the clays.

Recent development of these soils for cropping has been responsible for serious soil erosion. The morphological and chemical characteristics of the soils are such that degradation by erosion will expose soil horizons which are not conducive to infiltration of water, are difficult for plant roots to penetrate and have very low levels of nutrients such as nitrogen, phosphorus and potassium. Experience in the region has demonstrated that it is extremely difficult to revegetate these soils if they are eroded into the B horizon. Where erosion has been confined to the A horizon marked reduction and occasionally failure in crop growth has been observed. Several factors would be responsible for this, but the main factors are probably the loss of plant available water and nutrients associated with the reduced thickness of the A horizon.

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