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IV. SOILS

Previous Investigations Previous soil surveys in north-western Victoria have been confined largely to the irrigation districts along the River Murray at Woorinen (Taylor and Penman 1930), Nyah (Taylor *et al* 1933)., Merbein (Penman *et al* 1939), Mildura (Penman *et* al 1940), Robinvale (Skene 1940), Redcliffs (Hubble and Crocker 1941), and most recently at Woorinen (Churchward 1960). Zimmer (1937) has dealt with a larger area of non-irrigated soils in the extreme north-western comer of the State.

Parent Materials The soil parent materials are unconsolidated strata which range in texture from sand to clay.

Hills (1939) noted a series of lime-rich bands in a railway cutting through a dune to the north of Ouyen (Plate 3). He suggested that these bands were illuvial soil horizons and that the intervening layers were eluvial horizons. He farther postulated that a series of arid periods has occurred during which dune materials were deposited by wind action and that these periods were interspersed with more humid times when leaching took place on the new surfaces.

These interpretations have been confirmed by Butler and others who have studied layered landscapes in the Riverina, and adjacent country. Butler (1956) has further shown that not only the dunes but also the plains and other undulating land forms are composed of aeolian strata in which fossil soils can be recognized. He has named the clay parent material "parna". It is a calcareous dust which differs from loess in that it contains more clay than silt. Butler and Hutton (1956) have shown that parna has blanketed landscapes and that it occurs as pure parna or as a mixture with variable proportions of saltation material.[*] This mixture is usually found on and adjacent to the undulating land forms whilst pure parna is most widespread on the broader plains.

In agreement with Hills, Butler (1959) has postulated the occurrence of a series of arid periods in recent geological times. Each arid period began with an unstable phase during which soil parent materials were deposited, and it was followed by a stable phase during which the new surfaces were weathered, After an intensive stratigraphical. study, Butler and his co-workers designate the soils and fossil soils within a district as K_1, K_2, K_3, etc., in order of increasing age. Churchward (1960, 1961a) has recognized five K layers in the aeolian landscape of the Swan Hill district.

The criteria for recognizing separate soils are complex (Butler 1959, Churchward 1961a). They depend on the fact that, within the one soil, there is a normal transition of properties brought about by illuvial-eluvial processes; where a sequence of horizons is encountered which cannot be explained by these processes, separate soils exist. Recognition of the separate soils is frequently aided by considerable variation between them in properties such as the strength of structural development, the degree of leaching of lime, colour and texture. The variation in some properties is due to the variable amount of weathering the soils have undergone whilst existing at the surface.

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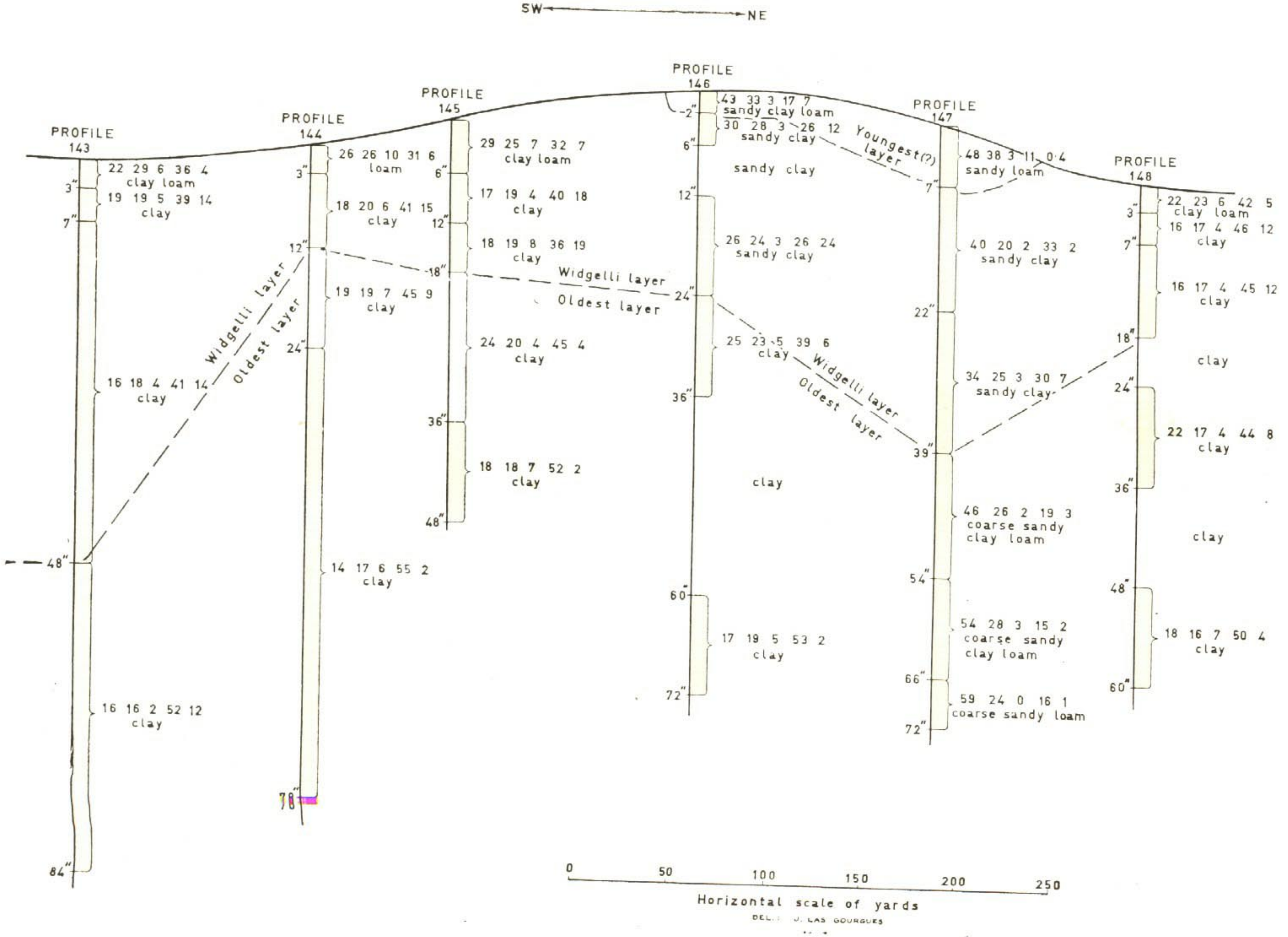
[*] Saltation material is too coarse to be raised by the wind into the atmosphere. Instead it bounds along the surface of the ground.

Fig 7 – Distribution, mechanical analyses and field textures of soil layers across a hummock near Birchip.



The following study is included as an example of the arrangement of soil layers within the region. Six profiles were examined across a hummock about 11 feet high, situated on a plain near Birchip, (see Figure 7). At least two, and possibly three soil layers were revealed. The sandy surfaces of profiles 146 and 147 are either the most recent deposit or A horizons developed by eluviation, and further stratigraphical studies would be needed to determine this. The predominant surface soil which varies in thickness from 12 to 48 inches corresponds with Widgelli parna which is the most recent parna deposited on a regional scale (Butler 1958). It shows a weak subangular blocky structure, a higher lime content than the layers above and below, and a variation in colour from brown to red. The oldest soil is met at a depth of from 12 to 48 inches and its A horizon was stripped prior to the deposition of the Widgelli parna. It has been relatively severely weathered, as shown by the strong angular blocky structure, the relatively low lime content, the mottled colours in which grey predominates, and by the presence of black, granular secondary minerals.

The texture of each soil layer varies according to its position on the landscape. The youngest (?) layer is a sandy clay loam on the hummock crest and a sandy loam on the north-eastern slope. The Widgelli layer is a sandy clay on the crest and north-eastern slope but a clay elsewhere. The oldest layer is a clay except on the north-eastern slope where it is a coarse sandy clay loam.

The realization that two or more soils are typically found within a few feet of the surface paves the way for more effective pedological studies in which an attempt is made to determine the prior state of the parent materials and the changes which have occurred in them (Butler 1958a).

Classification The most useful characteristic for classifying the soils for dryland farming is texture, which greatly influences the availability of nutrients and moisture. Surface texture is particularly important.

The nutrient status of the soils increases with increasing clay content. This can be seen in the wettest of years when moisture is a relatively minor limiting factor. Under these conditions, crop growth is vigorous on the finer-textured soils, and it becomes weaker as the soils become coarser.

By contrast, the coarser soils have the more favourable moisture characteristics under the prevailing climate. When nutrient deficiencies are a relatively minor factor these soils support the greater bulk of growth.

The better moisture supply to plants on the lighter soils can be explained by the greater depth to which they are penetrated by rainfall, with a consequent lower loss by evaporation than from the heavier soils. Evaporation from the surface is considerable, not only from bare fallows but also from the bare spaces within the relatively scant vegetation supported by the semi-arid climate. The variable depth of penetration of rain into soils of differing surface texture is shown in Table 5. These results are based on measurements of the percentage moisture by volume in only slightly disturbed surface, samples taken in north-western Victoria. Twenty points of rain (the average rainfall per wet day during the year) penetrates over three inches into an air-dry sand but only half an inch into an air-dry clay. Similar measurements have been recorded by Leeper (1957) who shows that soils of medium texture have penetration characteristics intermediate between those of the sands and clays.

Although the heavier soils can store more moisture (see available water at field capacity in Table 5), the importance of this factor is reduced because there is rarely sufficient rain to wet these soils to a significant depth. For example, one inch of rain penetrates only three inches into the clay.

Table 5 – Moisture characteristics of topsoils within the region

Field Texture	Bulk Density g/ml	Mechanical analysis %				% Moisture by Volume				Depth (inches) of Penetration of Rainfall into Air Dry Soil		
		Coarse Sand	Fine Sand	Silt	Clay	Air Dry	Wilting Point	Field Capacity	Available at Field Capacity	20 pts	50 pts	100 pts
Sand	1.6	53	41	0.3	3	0.3	1.7	6.3	4.6	3.3	8.3	16.6
Clay	1.0	7	18	26	45	4.5	20	40	20	0.6	1.4	2.8

In moister parts of Victoria deep sands are regarded as droughty soils because, having a low moisture storage capacity, they lose much water by percolation beyond the root zone of plants. However, owing to the low and somewhat evenly-distributed rainfall in north-western Victoria (Figure 2), the loss of moisture from sands within the region is much less serious, and it can be virtually discounted when deep-rooted species such as lucerne are grown.

The classification of the major soils is summarised in Table 6. The primary division is into four textural groups according to surface texture, namely sands, sandy loams, light clays and heavy clays. There is an additional group, the saline soils, in which the salt content is high enough to exclude native vegetation other than halophytes. The saline soils are of variable texture at the surface and at depth.

The textural groups are further divided into morphological groups according to the nature of the textural change with depth. Abrupt texture changes are those which occur within 1 inch, i.e., sharp enough to form a distinct line of demarcation (Plates 4, 5, 7). There are two morphological groups within the sands, the deep sands in which there is no textural change with depth, and the sands of Group D which have sandy loam or sandy clay loam subsoils (Plate 4). There are four morphological groups within the sandy loams, Group A in which there is a gradual texture increase, typically over several inches, to sandy clay or sandy clay loam (Plate 6), Group B in which there is an abrupt change to sandy clay or sandy clay loam (Plate 5), Group C in which there is an abrupt change to clay (Plate 7), and finally the limestone soils which are shallow sandy loams overlying a limestone pavement. There is no texture increase with depth in the light clays and the heavy clays, apart perhaps from a slight increase below the A, horizon.

The sands of Group D have been further subdivided into sub-groups according to colour, into red, reddish yellow and white sands.

The soils are pedocals, although the deep sands are marginal in this respect. The presence of free lime indicates that the rainfall has been low since the parent materials were deposited.

Plate 4 – Reddish yellow sand of Group D

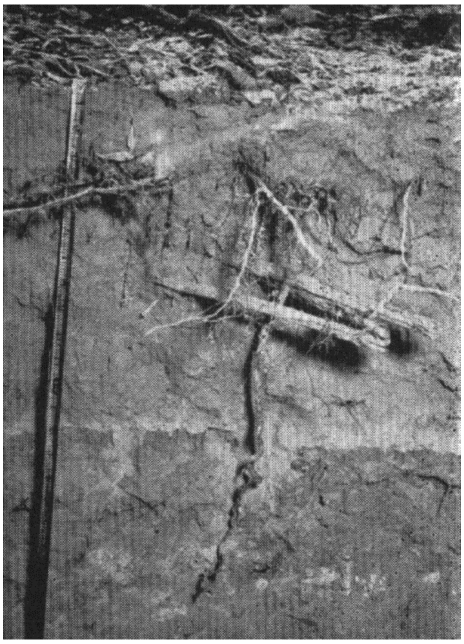


Plate 5 – Sandy loam of Group B

The relationships between the morphological groups and the Australian great soil groups recognised by Stephens (1962) are shown in Table 6. The relationships with soil series recognised in detailed investigations in the irrigation areas are also shown. The sandy loams of Group A, the limestone soils, and the sands of Group D correspond with the solonised brown soils (synonymous with "mallee soils"). The sandy foams of Group B have either a level or a domed textural boundary ; they correspond with the solonetz soils when domed and with the red brown earths when the boundary is level. The sandy loams of Group C can be placed with the red brown earths, the light clays with the brown soils of heavy texture, the heavy clays with the grey soils of heavy texture and the saline soils with the solonchaks. The deep sands do not correspond with any great soil group ; although iron has been leached from the upper horizons, indicating podzolisation, the reaction is not strongly acidic and thus the soils cannot be regarded as podzols.

Physical and Chemical Analyses A comprehensive series of analyses was done on the soils, and the techniques used are described in Appendix 1. The various soils are compared in terms of their physical and chemical characteristics in Table 7 (mechanical analysis), Figure 8 (pH), Figure 9 (exchangeable metal cations), Figure 10 (nitrogen), Figure 11 (potassium), Figure 12 (phosphorus), Figure 13 (chloride), and Figure 14 (calcium carbonate). The results confirm field observation in showing that the nutrient status increases with increasmig heaviness of texture.

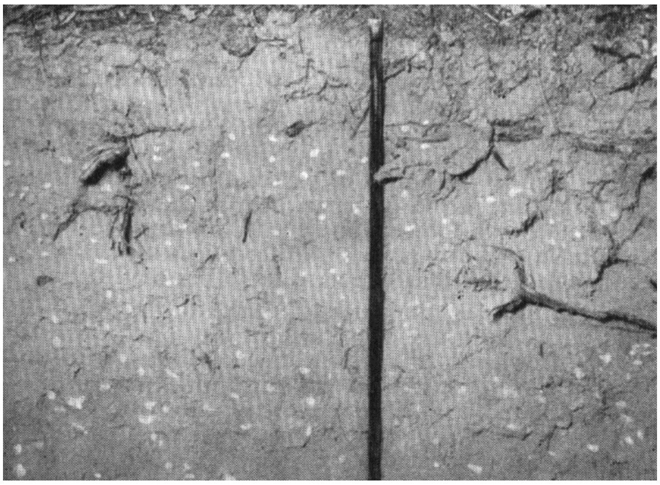


Plate 6 – Sandy loam of Group A

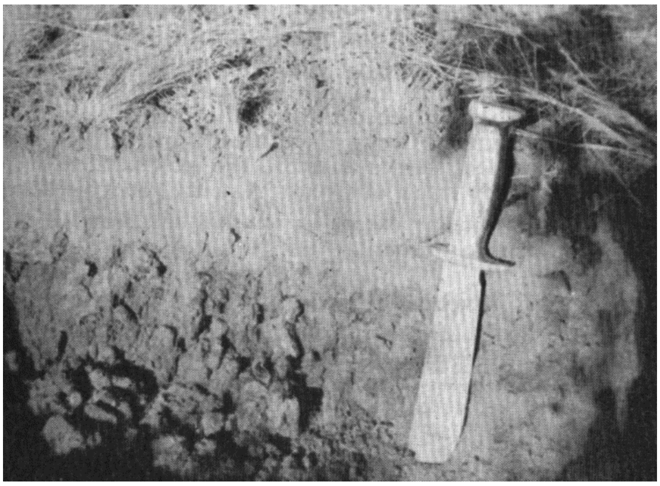


Plate 7 – Sandy loam of Group C

Samples were taken from virgin sites because cultivated soils have been modified to varying degrees both chemically and physically. Difficulty was encountered in finding suitable sites within farming districts because of the widespread effects of wind erosion. Road easements and small timber reserves were found to be unsatisfactory sites owing to drift accumulation so that sampling had to be confined to relatively large timber reserves. Care was needed to avoid drift along the western margins.

Mechanical Analysis Particle size analyses of profiles representative of the various morphological groups are shown in Table 7 in terms of percentages of coarse sand, fine sand, silt and clay. Values range from almost 100 per cent sand throughout the profile in the deep sands to about 60 per cent clay throughout the heavy clays. The silt content of the profiles formed on saltation deposits is low. In several profiles it averaged less than 1 per cent in the sands and about 1 per cent in the sandy loams. This is to be expected because, when saltation took place, particles of silt size would be removed by wind winnowing. Values for silt are higher in the soils formed from parna, as shown by the mechanical analyses done on nine light clay profiles. In these soils silt averaged 7 per cent throughout the profile and it ranged from 4 to 16 per cent.

Table 7 shows that the proportion of coarse to fine sand remains fairly constant with depth. The heavy clay and light clay profiles are representative of their groups in showing that their sand fraction is dominated by fine sand. However the proportion of coarse to fine sand varies considerably in lighter soils so that the single profiles shown are not representative. The white sands of the Big Desert and Berrook land systems, both deep sands and sands of Group D, generally show a marked predominance of one or the other sand fraction. The four sandy loam morphological groups and the red and reddish yellow sands of Group D frequently have approximately equal proportions, but either coarse or fine sand sometimes predominates.

Table 6 – Classification of Soils

Textural Group	Nature of Textural Change with Depth	Morphological Group	Morphological Sub-Group	Relationships to Australian Great Soil Groups	Relationship to Soil Series
Sands	No change	Deep sands	White sands		
	Change to sandy loam or sandy clay loam	Group D	Red sand Reddish-yellow sands White Sands	Solonized brown soils	Murray, Berri, Barmera, Tyntunder, Tatchera, Winkie
Sandy loams	Gradual change to sandy clay or sandy clay loam.	Group A		Solonized brown soils	Berri, Barmera, Nookamka, Tatchera (lime-free at surface), Moorook, Coomealla, Sandilong (lime at surface)
	Abrupt change to sandy clay or sandy clay loam	Group B		Solonetz Red brown earths	
	Abrupt change to clay	Group C		Red brown earths	
	Abrupt change at shallow depth to limestone	Limestone soils		Solonized brown soils	
Light clays	No change	Light clays		Brown soils of heavy texture	Belar, Irymple, Vinifera, Nyah
Heavy clays	No change	Heavy clays		Grey soils of heavy texture	Pomona
Variable	Variable	Saline soils		Solonchaks	

Soil pH The results of pH analyses are set out in Figure 8. The surface horizons of most of the soils are markedly alkaline, the exceptions being the deep sands and the sands of Group D in which the average pH values approach neutrality. In addition, the sandy loams of Group B are usually less alkaline at the surface than other soils of equivalent surface texture. The most alkaline surfaces occur in the light clays, the sandy loams of Groups A and C, and the limestone soils.

Subsoils are highly alkaline except in some of the deep sands where the pH at depth is approximately neutral.

Exchangeable Metal Cations Figure 9 shows that total exchangeable metal cations at the surface range from very low values of 6 milliequivalents per cent. or less in the sands to 28 milliequivalents per cent. in the heavy clays. Subsoils show a similar trend, with higher values than those at the surface, except where there is no texture increase with depth.

In all soils calcium predominates on the exchange complex at the surface, and this effect is most marked in the lighter soils. Except in the deep sands there is a decrease in the proportion of calcium with depth, and there is usually a co-dominance of calcium, magnesium and sodium in subsoils. The proportion of potassium is low throughout the profiles.

Nitrogen The semi-arid climate is reflected by the low nitrogen content of the soils (Figure 10). At the surface, nitrogen ranges from 0.06 per cent or less in the sands to 0.14 per cent in the light clays. The lower quantities in subsoils show only a slight increase with increasing texture.

Potassium Figure 11 shows the percentage potassium extracted from soils by concentrated hydrochloric acid. At the surface potassium increases from low values in the sands (averaging 0.15 per cent) to satisfactory values in the light clays (averaging 0.85 per cent). The higher levels in subsoils are similarly correlated with texture.

Phosphorus Figure 12 shows that the phosphorus content of the soils is low and again correlated with texture. Average surface levels range from 0.006 per cent in the sands to 0.02 per cent in the light clays. The phosphorus contents decrease with depth.

Chloride The percentage chloride (Figure 13) is a good guide to the soluble salt content of the soils. At the surface, the chloride content is low in the sands (average 0.002 per cent) and the sandy loams (0.003 per cent), higher in the light clays (0.01 per cent) and higher still in the heavy clays (0.7 per cent).

In subsoils the values are higher, except in the deep sands, and the range is wider, from 0.001 per cent in the deep sands to 0.29 per cent in the puffs of gilgaied light clays.

The chloride content of the saline soils sampled ranged from 0.009 to 4.5 per cent at the surface and from 0.4 to 0.9 per cent in subsoils.

Calcium Carbonate (lime) Carbonates determined in the laboratory have been expressed as calcium carbonate (see Figure 14). Various workers, for example Northcote (1951), have shown that the carbonates in soils similar to and adjacent to those of north-western Victoria consist mainly of calcium carbonate, with smaller proportions of magnesium carbonate.

The average lime content at the surface of the sands and the sandy loams of Groups B and C is less than 1 per cent. It is higher, though variable, in the sandy loams of Group A and the limestone soils. The light clay topsoils have a relatively high lime content, averaging 5 per cent.

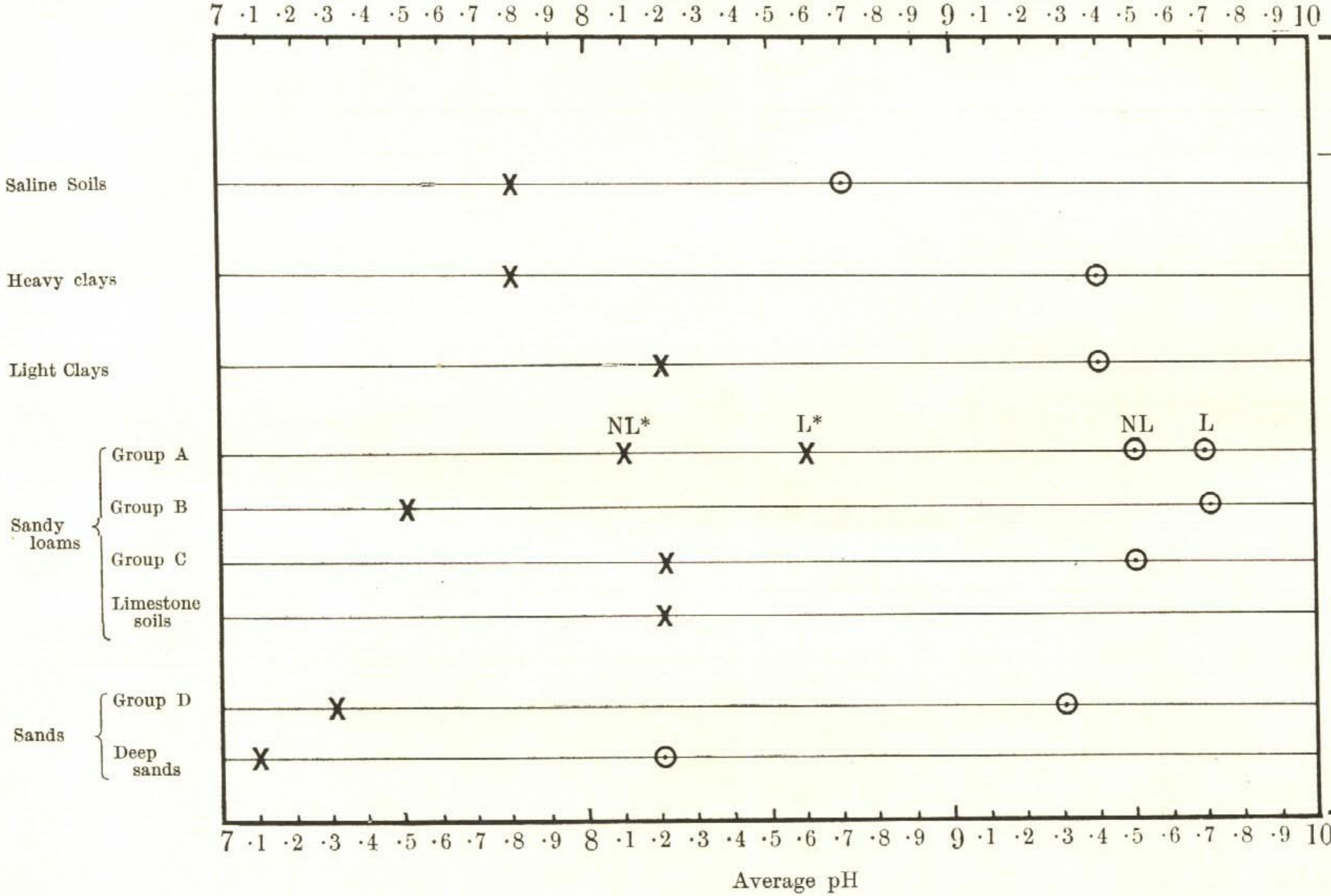
Table 7 – Mechanical analysis data for soils

Morphological Group		Surface: Profile No.	Surface: Sample Depth (in)	Surface: Field Texture	Surface: Coarse Sand (%)	Surface: Fine Sand (%)	Surface: Silt (%)	Surface: Clay (%)	Surface: Fine Earth Lime (%)	Surface: Gravel (Lime) (%)	Subsoil: Sample Depth (in)	Subsoil: Field Texture	Subsoil: Coarse Sand (%)	Subsoil: Fine Sand (%)	Subsoil: Silt (%)	Subsoil: Clay (%)	Subsoil: Fine Earth Lime (%)	Subsoil: Gravel (Lime) (%)
Heavy clays		119	0-3	Heavy clay	7	14	14	59	3	1	36-48	Heavy clay	5	13	8	66	4	5
Light clays		108(a) (puff)	0-2	Clay	17	35	7	35	7	-	12-24	Clay	16	26	4	41	10	-
Sandy loams	Group A	52	2-5	Sandy loam	41	38	2	15	2	-	10-24	Sandy clay	29	31	1	19	20	5
Sandy loams	Group B	42	1½-3	Sandy loam	46	38	2	11	2	-	6-12	Sandy clay	38	29	2	29	3	-
											48-60	Sandy clay	25	15	1	25	36	5
Sandy loams	Group C	51	1½-4	Sandy clay loam	29	34	12	20	2	-	4-6	Clay	19	27	11	37	2	-
											18-24	Clay	13	14	5	47	16	25
Sandy loams	Shallow on limestone	74	0-1½	Sandy loam	30	39	5	20	1	-								
Sands	Deep sands	71	0-3	Sand	67	29	0.4	3	0.6	-	48-60	Sand	64	34	-	-	0.7	-
Sands	Group D	47	1½-3	Sand	38	57	1	5	0.3		48-60	Sandy loam	35	57	0.4	11	2	-

NB – indicates nil.

Percentages are of fine earth except for gravel which is percentage of field sample

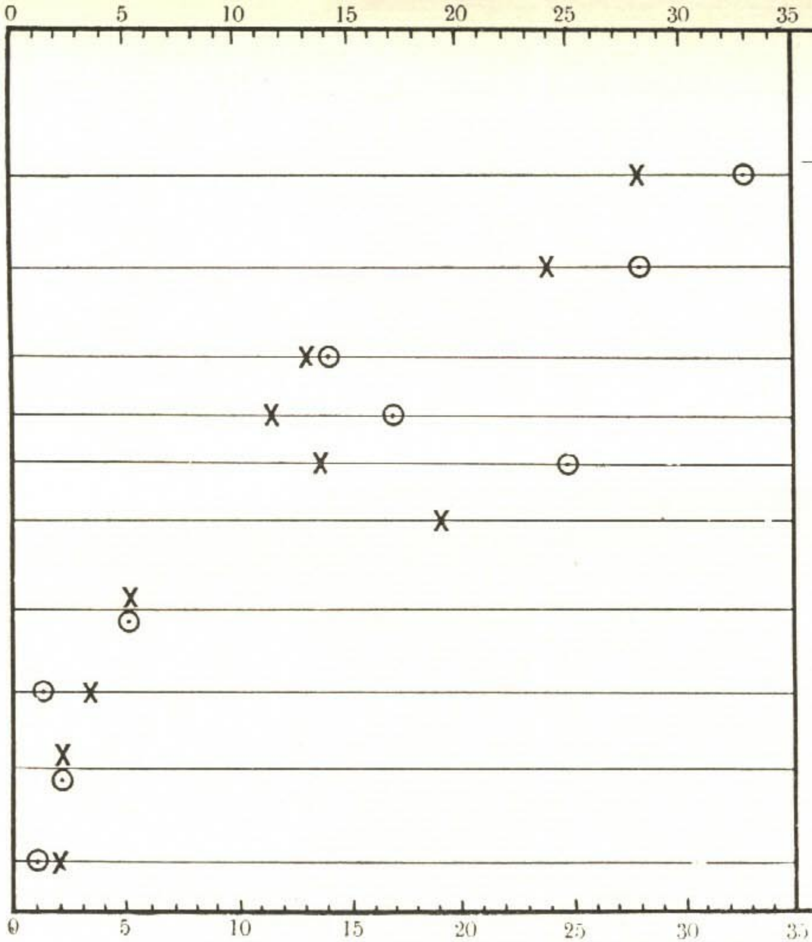
Fig 8 – Soil pH



No. of Profiles from which Average Taken.	Range.	
	Surface.	Subsoil.
3	6·9–8·5	8·5–8·8
1	7·8	9·4
8	7·3–8·7	8·9–9·8
NL 15	7·5–8·4	7·7–10·0
L 7	8·4–8·8	9·2–10·0
14	6·4–8·4	9·3–10·1
4	7·7–8·7	9·0–10·
2	8·0–8·4	—
9	6·8–7·9	8·9–9·7
5	6·8–7·8	6·6–9·2

×—at surface. ⊙—maximum in subsoils. L* refers to soils with visible lime at surface. NL refers to soils without visible lime at surface.

Fig 9 – Exchangeable metal cations in soils

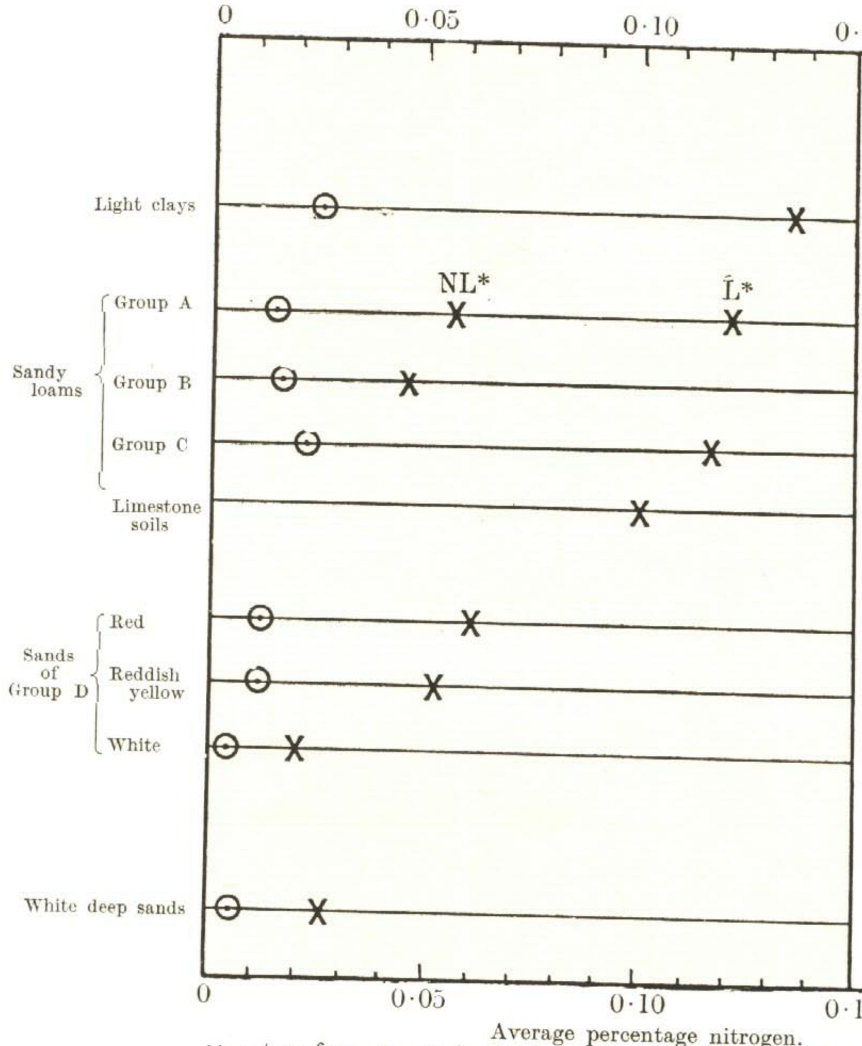


Average total exchangeable metal cations m.e. %
×—at surface. ⊙ in subsoils.

Soil	No. of Profiles from which Average Taken.	Range m.e. %		Percentage of Each Metal Cation.							
				Surface.				Subsoil.			
		Surface.	Subsoil.	Ca.	Mg.	K.	Na.	Ca.	Mg.	K.	Na.
Heavy clays	1	27·9	32·9	57	23	14	6	22	43	6	29
Light clays	4	14·1–34·3	16·5–35·6	66	20	8	6	38	33	4	25
Sandy loams: Group A	7	9·9–15·9	9·2–19·4	75	18	6	1	31	34	8	27
Sandy loams: Group B	2	10·4–12·8	15·4–18·7	70	22	7	2	30	41	8	21
Sandy loams: Group C	1	13·6	24·8	68	19	12	1	32	38	8	23
Sandy loams: Limestone soils	1	19·1	..	63	30	6	1	..	..	..	..
Sands of Group D: Red	3*	3·9–6·2	4·5–5·9	84	10	5	1	83	12	3	2
Sands of Group D: Reddish yellow	4*	2·0–5·9	1·2–2·2	83	11	5	1	71	20	6	3
Sands of Group D: White	2*	2·0–2·7	1·1–3·5	86	9	3	2	82	13	4	2
White deep sands	3	1·3–3·0	0·8–1·0	87	8	3	3	79	12	4	5

* Subsoil samples taken above textural boundary.

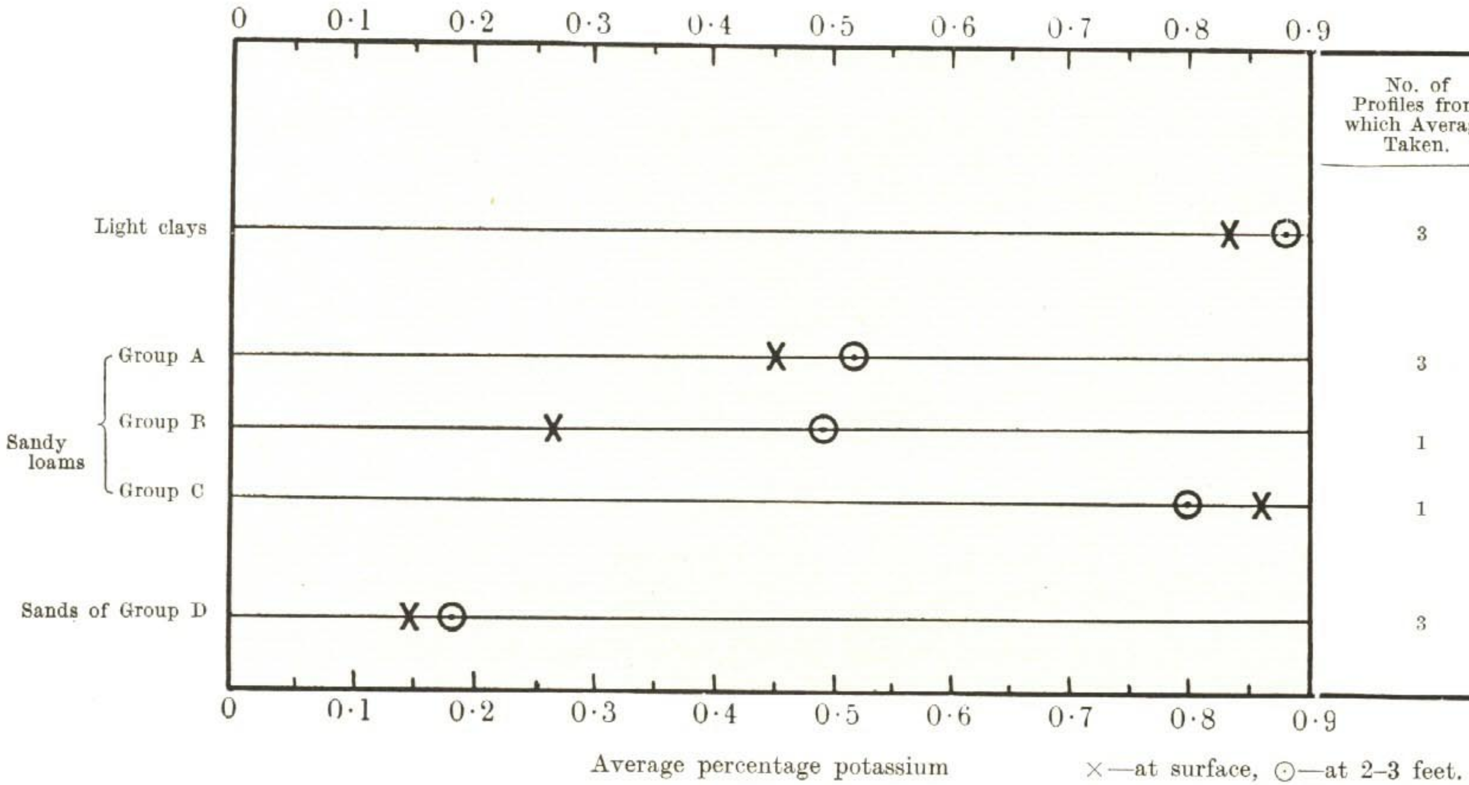
Fig 10 – Nitrogen in soils



	No. of Profiles from which Average Taken.	Range %. Surface.	Range %. Subsoil.
Light clays	5	0·083–0·241	0·017–0·034
Sandy loams: Group A	NL 2 L 3	0·044–0·069 0·069–0·195	0·013–0·016
Sandy loams: Group B	4	0·033–0·065	0·012–0·023
Sandy loams: Group C	2	0·054–0·178	0·019–0·025
Limestone soils	2	0·097–0·099	..
Sands of Group D: Red	3	0·032–0·101	0·005–0·018
Sands of Group D: Reddish yellow	4	0·020–0·101	0·006–0·017
Sands of Group D: White	2	0·018–0·022	0·004–0·005
White deep sands	3	0·012–0·026	0·003–0·004

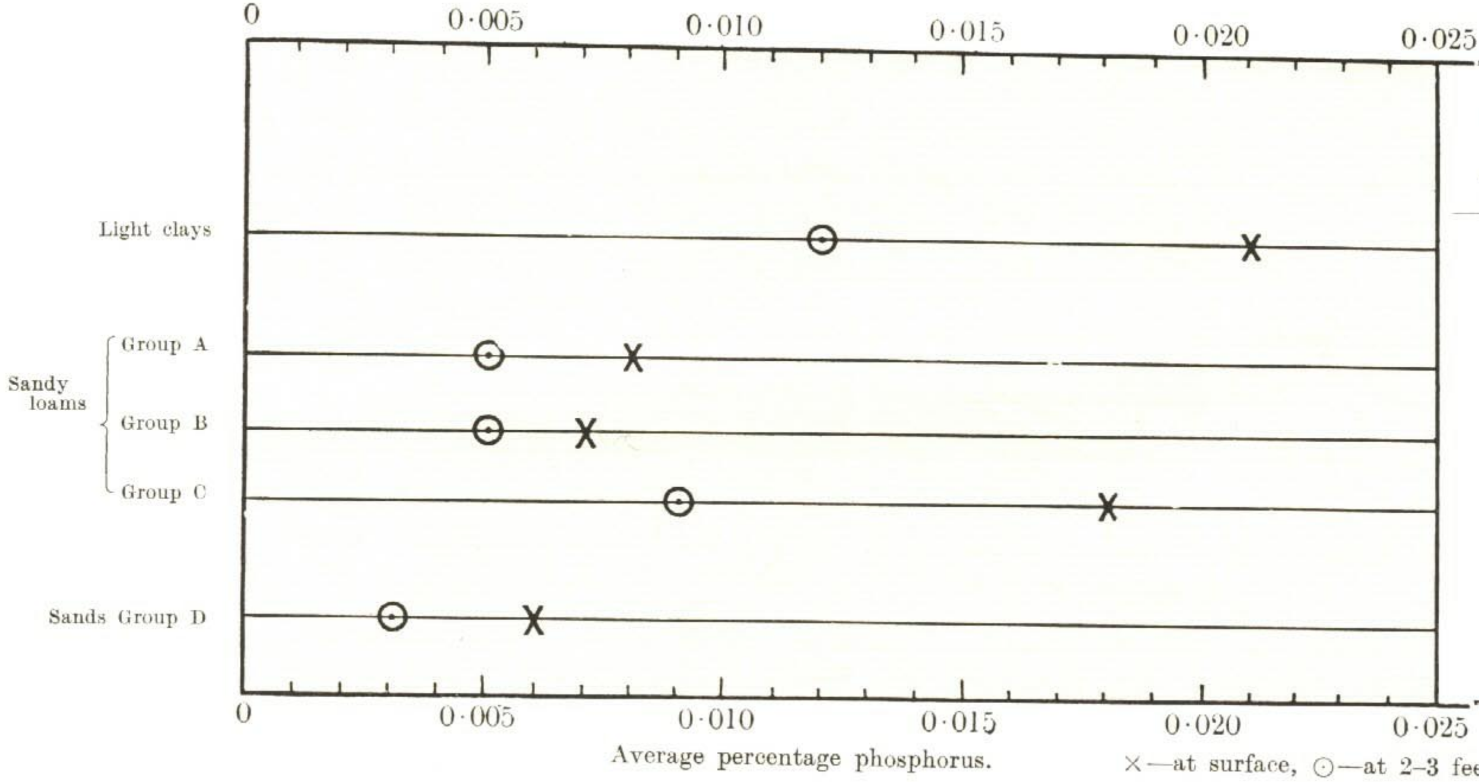
×—at surface, ⊙—at 2–3 feet. L* refers to soils with visible lime at surface. NL refers to soils without visible lime at surface.

Fig 11 – Potassium in soils



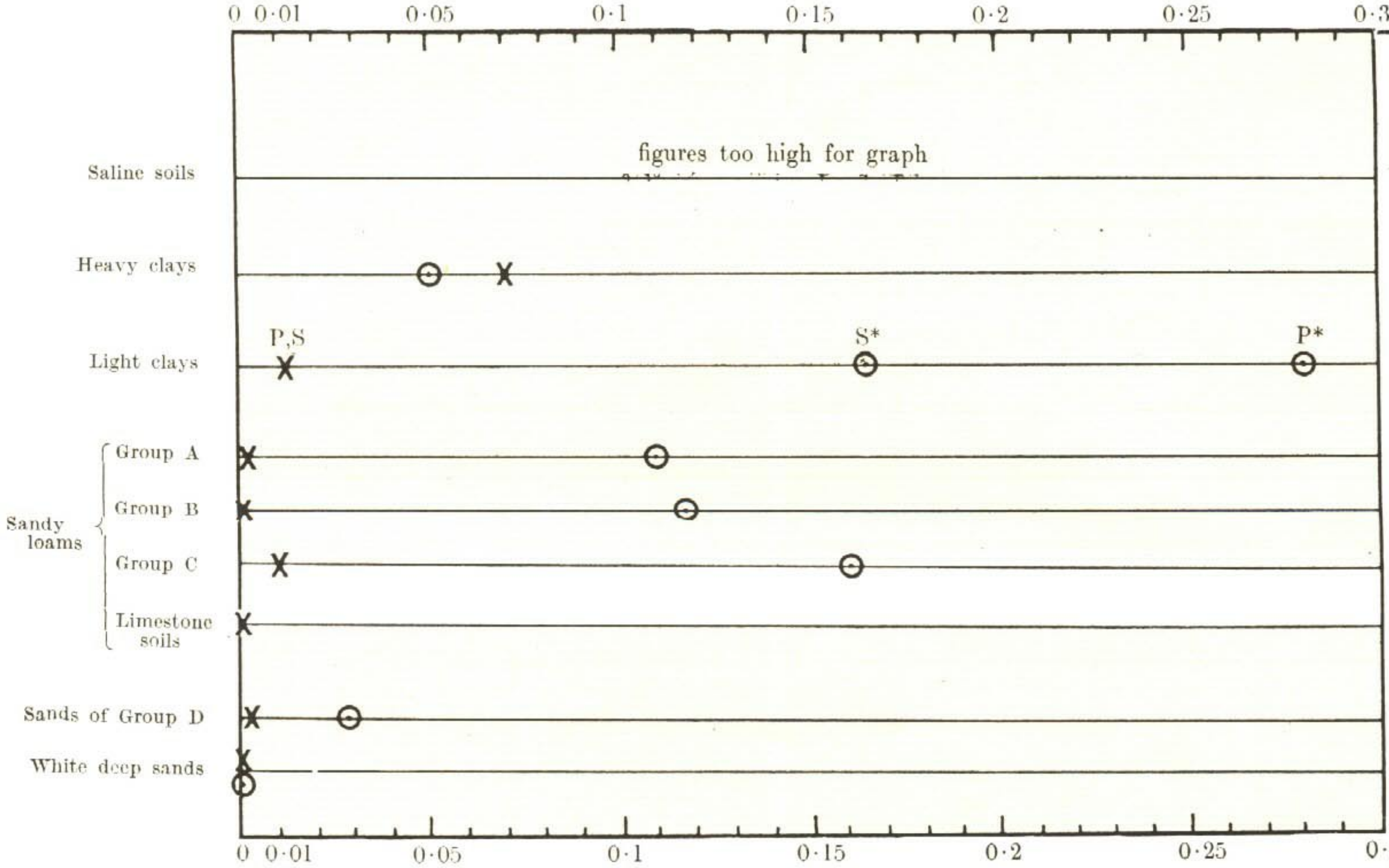
No. of Profiles from which Average Taken.	Range %.	
	Surface.	Subsoil.
3	0·68–1·03	0·64–1·30
3	0·35–0·52	0·46–0·56
1	0·26	0·49
1	0·86	0·80
3	0·07–0·20	0·07–0·37

Fig 12 – Phosphorus in soils



No. of Profiles from which Average Taken.	Range %.	
	Surface.	Subsoil.
3	0·015–0·031	0·008–0·018
3	0·005–0·012	0·004–0·006
1	0·007	0·005
1	0·018	0·009
3	0·002–0·009	0·001–0·005

Fig 13 – Chloride in soils

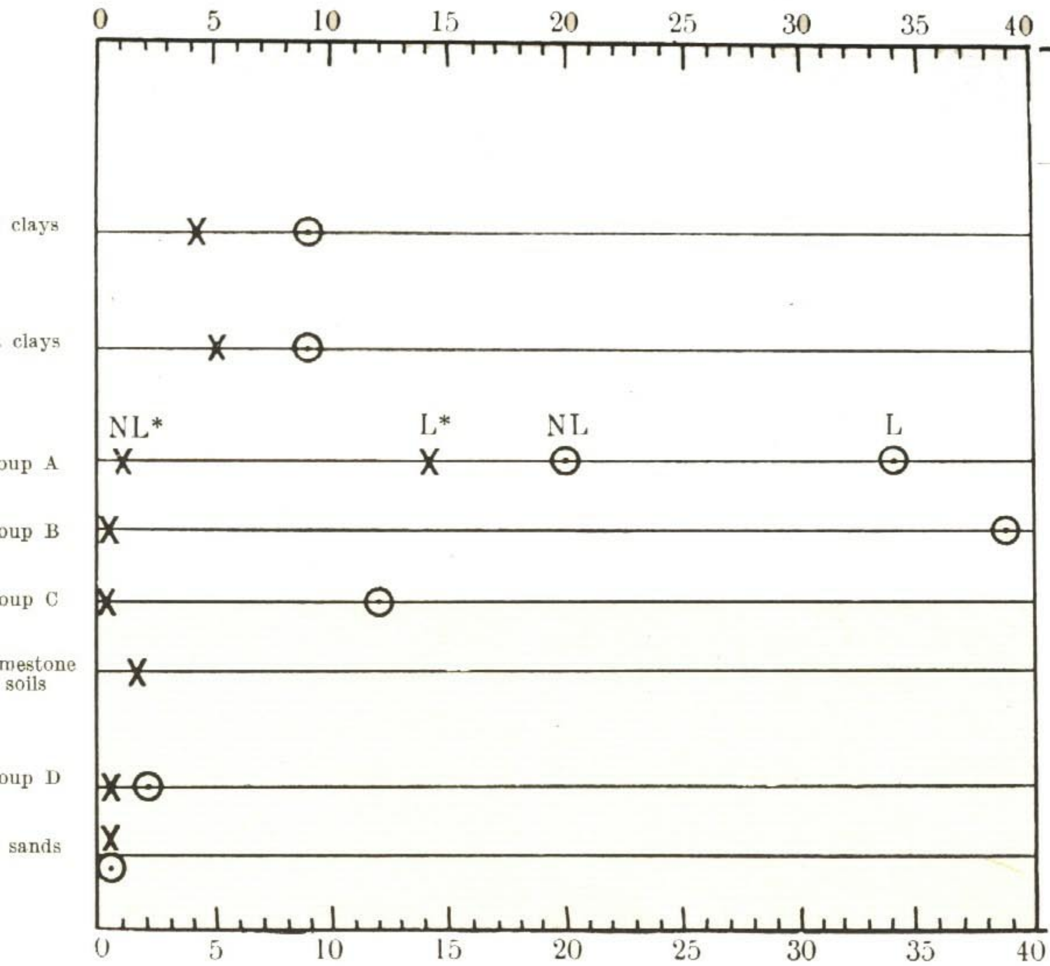


No. of Profiles from which Average Taken.	Range %.	
	Surface.	Subsoil.
3	0·009–4·5	0·412–0·93
1	0·07	0·05
6	0·001–0·022	P 0·216–0·331 S 0·144–0·177
22	0–0·010	0·014–0·268
14	0–0·006	0·061–0·187
4	0·007–0·020	0·024–0·337
1	0·002	. .
6	0–0·007	0·001–0·099
5	0	0–0·002

Average percentage chloride.
×—at surface, ⊙—maximum in subsoils.

P* refers to gilgai puffs, S refers to gilgai shelves.

Fig 14 – Calcium carbonate in soils (as fine earth plus gravel expressed as percentage of field sample)



No. of Profiles from which Average Taken.	Range %.	
	Surface.	Subsoil.
1	4	9
5	2–7	8–11
NL 5 L 4	NL < 1–3 L 7–27	NL 7–33 L 17–44
5	0–1	14–48
4	0–2	5–37
2	1–2	..
10	0–1	1–4
5	0·3–1	0·1–0·7

Average percentage calcium carbonate.
×—at surface, ⊙ maximum in subsoils.

L* refers to soils with visible lime at surface.
NL refers to soils without visible lime at surface.

The lime content increases with depth, except in the deep sands. The sandy clay and sandy clay loam subsoils of Groups A and B contain the largest quantities, averaging between 20 and 39 per cent of the field sample in the soils examined.

Most of the lime in soils occurs within the fine earth fraction (less than 2 mm.). Coarser material, or limestone, occurs as nodules, angular stones and less often in sheet form. The sandy clay and sandy clay loam subsoils of Groups A and B contain the largest quantities of limestone, as much as half the field sample in one profile analysed.

Morphological, analytical and agronomic features of the soff units In this section there is a generalized account of the physical and chemical characteristics of each morphological group and sub-group, together with detailed field descriptions of representative profiles. Analytical data for single profiles are given in appendix III.

The agronomic features of the various soils are discussed on the basis of morphological and analytical characteristics. Only generalized statements can be made in this section because the productivity of a soil is affected by factors other than its own nature, and particularly by the climatic factor which varies considerably across the region. Agronomy is discussed only in terms of the general regional climate and the productivity of the soils in the different climatic zones within the region is examined in the discussion of individual land systems (Chapter VI).

Sands These soils have been subdivided into two morphological groups, the deep sands and the sands of Group D, on the basis of the presence or absence of heavier subsoils.

The sands vary widely in fertility and the variation can most readily be assessed by noting colour differences. The diagnostic horizon for colour determination is the layer beneath the relatively shallow and browner surface zone of organic matter accumulation. In order of decreasing fertility, the range of colour is from red-brown, through red, yellowish red, reddish yellow to white.

At the reconnaissance level, three types of sand have been recognized within the soils of Group D. Together with typical Munsell notations these are red sands (2.5 YR 4/8, 5 YR 4/8, 10 R 5/8), reddish yellow sands (5 YR 6/8, 7.5 YR 7/6, 10 YR 8/6), and white sands which cover a relatively narrow range around 10 YR 8/4. The deep sands contain white sands only.

The field evidence of increasing fertility from the white through the reddish yellow to the red sands is reflected by the laboratory data for exchangeable metal cations and nitrogen (Figures 9 and 10). However, these analyses can be regarded as only a tentative guide to the variation in nutrient status. A better assessment is required, based on analyses from a larger number of replicated samples.

Deep sands These are confined to the Big Desert and Berrook land systems where they predominate on all landscape positions, namely on jumbled dunes, dunes and plains. The A_1 horizon is a pale-brown sand to loamy sand about 6 inches deep. It merges into white sand which ranges in thickness from about 2 feet to several feet. Below these loose horizons there is a slightly more compact yellow sand. Lime may be present at depth as flecks or it may be absent. The following typical profile occurs in the Big Desert to the south of Murrayville, on the crest of a dune carrying scrub mallee:

0-6 inches	pale-brown (10 YR 6/3) loamy sand, weak crumb, loose, diffuse change to
6-30 inches	white (10 YR 8/4) sand, apedal, loose, diffuse change to
30-60 inches	yellow (10 YR 8/6) sand, apedal, weakly compacted.

The surface horizons are approximately neutral whilst the subsoils may be neutral or alkaline. Alkaline subsoils appear to occur mainly in the lower sites. Laboratory analyses show extremely low values for all nutrients.

Because of their low fertility the deep sands generally have been avoided in opening up of settlements. In those occasional areas where the native vegetation has been removed, no satisfactory form of land use has been achieved. Consequently, the wind has removed the loose sandy surfaces to variable depth. Frequently several feet have been removed to expose the more compact yellows. The fertility is too low for regular cropping. Pasture trials with diary soils to the south of the region have shown the need for heavy dressings of superphosphate and frequently of lime, with the addition of copper and zinc.

The deep sands have relatively favourable moisture characteristics under the semi-arid climate, provided they support deep-rooted species. Although there is no impeding horizon with depth, field observation suggests that there is little loss of moisture by deep percolation under the deep-rooted native vegetation.

Sands of Group D have sandy loam or sandy clay loam subsoils which are generally encountered at a depth of between 2 and 4 feet. The A, horizon is, typically about 6 inches thick and it gives way to deeper horizons of sand ,which have been classified as red, reddish yellow or white. In contrast to the loose upper horizons, the heavier subsoils are compact and they contain lime which usually increases in amount with increasing texture. The .morphological group is illustrated by the following profile which occurs on the crest of a dune in the Parish of Tiega, County Karkarooc. The native vegetation is savannah mallee:

0-11 inches	brown (7.5 YR 5/6) sand, weak platy, firm, abrupt change to
11-6 inches	yellowish brown (5 YR 5/8) sand, weak crumb, soft, diffuse change to
6-28 inches	reddish yellow (5 YR 6/8) sand, apedal, soft, diffuse change to
28-30 inches	off-white (7.5 YR 8/6) sand, apedal, soft, abrupt change to
30-60 inches	light red (2 - 5 YR 6/8) sandy loam, apedal, hard when dry, lime in occasional soft pockets.

The **red sands** occur on dunes and on the upper slopes of relatively steep hummocks and ridges. They are most widespread in the Millewa land system where they are alkaline throughout the profile and, unlike other soils of Group D, they have diffuse textural boundaries. Red sands occur occasionally in the Central Mallee, Hopetoun and Tempy land systems. Here the textural boundary 'is sharp and either level or irregular, whilst the pH is either neutral at the surface and alkaline at depth, or alkaline throughout.

On the dunes the over-all profile texture of the red sands becomes heavier from the upper to the lower slopes. The surface texture is sand at the crest and it gradually increases in clay content to become a sandy loam at the base. In addition the subsoil texture becomes both heavier (from sandy loam to sandy clay loam) and shallower from the crest to the base where the profiles merge into sandy loams of Groups A and B.

The **reddish yellow sands** also occur on dunes and on the upper slopes of relatively steep hummocks and ridges. They are the most widespread soils of Group D in the Central Mallee, Hopetoun and Tempy land systems. The pH is variable at the surface which is either neutral or alkaline, whilst subsoils are invariably alkaline. The textural boundary is abrupt and either level or irregular. As in the red sands, the overall profile texture increases from the crest to the base of the dunes.

The **white sands** of Group D are confined to low sites on plains in the Big Desert land system. The pH is neutral at the surface, alkaline at depth within the A horizons and highly alkaline in the B horizons. The latter are of sandy loam texture and the textural boundary is abrupt and irregular. Intergrades with the deep sands have been noted in which there are "floaters" of sandy loam texture at depth i.e. pockets of sandy loam surrounded by sand.

Although laboratory analyses and field observations show an increase in fertility from the white through the reddish yellow to the red sands, even the latter are of lower fertility than soils with a surface texture of sandy loam or heavier. Crop yields on the reddish yellow sands have declined seriously and not only phosphate but also nitrogenous fertilizer is usually required for satisfactory cereal growth. Although more variable and less acute, the same problems occur on the more fertile red sands.

The reddish yellow and red sands have suffered severe wind erosion which has removed the loose A horizons to variable depth, even exposing the compact subsoils in places. The most suitable species available for maintaining stability is lucerne which, being a legume, can make good growth under the low nitrogen levels, and being a perennial can provide a cover throughout the year. The potassium content is low at the surface and even lower at depth within the A horizons, whilst the heavier subsoils contain somewhat higher quantities. The small concentration of potassium in the A, horizons has, on the average, been removed by erosion. Under these conditions it is surprising that no responses o this nutrient have been recorded, particularly with shallow-rooted species in situations where the A horizons are relatively deep. It is possible that much of the potassium required for lucerne growth is obtained from the heavier-textured subsoils.

The white sands of Group D in the Big Desert land system have not beer cleared to any extent. Their land-use features are similar to those of the surrounding white deep sands, although their potassium content may be better owing to their heavier-textured subsoils.

As with the deep sands, the sands of Group D have relatively favourable moisture characteristics under the semi-arid climate, provided deep-rooted species are used. Moisture penetrates relatively deeply and it is temporarily held up by the heavier-textured subsoils, as indicated by the bleached horizon immediately above the textural boundary. The performance of these soils would be impaired if water were lost by percolation downslope within the bleached horizon. This has occurred on dunes in the moister southern districts, under fallow or where crop or pasture growth is Door, as indicated by the development of salting in low sites. The loss of moisture can be minimized by maintaining a vigorous cover of lucerne on the dunes.

Sandy Loams The surface texture of these soils is sandy loam, or less frequently sandy clay loam. They have been subdivided into four morphological groups according to the nature of textural changes with depth, namely, sandy loams of Groups A, B and C and shallow sandy loams on limestone.

Sandy loams of Group A are the most widespread soils in the region and they are most commonly found on interdune plains and on the lower 'slopes of hummocks and ridges. Profiles show a gradual field texture increase with depth to sandy clay loam or sandy clay subsoils. However, mechanical analyses have shown that the increase in clay content with depth is small and sometimes there is no increase. Mechanical analyses were done on eight profiles and the largest increase in clay observed was 10 per cent (from 15 per cent at the surface to 25 per cent, at depth) whilst the average increase was 4 per cent. The heavier field texture in subsoils appears to be due largely to the increase in fine earth lime content with depth, as suggested by Northcote (1951).

The colour of topsoils varies widely from red brown, yellowish brown and brown to grey brown and occasionally to grey. There is less variation in subsoils which range from reddish yellow through yellowish-red to red.

The soils contain abundant lime, usually as a mixture of fine earth material and angular stones or nodules. The largest amounts of lime, occur in subsoils where the maximum quantities in the nine profiles analysed averaged 27 per cent of the field sample. However, fine earth lime is encountered at variable depth, even reaching the surface in what are known as "limey" soils. The latter usually occur in relatively small patches which are noticeable on fallows, because they are duller than surrounding soils. However, they sometimes occur as relatively large discrete areas many acres in extent.

Topsoils are alkaline, with higher-than-average values where lime occurs at the surface. subsoils are highly alkaline. The following representative profile occurs on the lower slope of a hummock beneath mallee vegetation in the Parish of Tiega, County of Karkarooc:

0-11 inches	brown (7.5 YR 5/6) sandy loam, weak platy, brittle when dry, abrupt change to
11-6 inches	yellowish brown (5 YR 5/8) sandy loam, weak subangular blocky, soft, diffuse change to
6-12 inches	reddish yellow (5 YR 6/6) sandy clay loam, weak subangular blocky, firm, finely dispersed lime present, diffuse change to
12-60 inches	reddish yellow (5 YR 7/8) sandy clay compact, lime abundant as fine earth material, nodules and angular stones.

The sandy loams of Group A are widely cropped and they are of moderate fertility as indicated by the levels of nitrogen, potassium and exchangeable metal cations. The high chloride contents in subsoils indicate the likelihood of salting damage should waterlogging occur.

Field observation indicates that the amount of moisture available to crops and pastures is intermediate between that on the sands and on the light clays. Under the prevailing climate, moisture does not usually penetrate to a great depth, even under bare fallows. For example observations taken over a period of years on these soils at Walpeup where the average annual rainfall is approximately 121 inches show that most of the moisture conserved in bare fallows is held at a depth of between 6 and 24 inches (Sims and Mann, unpublished data). The depth of penetration would be shallower in the northern part of the region (10 inches average annual rainfall) and deeper in the southern part (14 inches). Under pasture the depth of penetration would be considerably less than under fallow and thus the soils are well suited to relatively shallow-rooted annual pastures.

Following adequate rainfall the growth of cereals on soils with lime at the surface is greater than average, due probably to the relatively high nitrogen content at the surface (Figure 10). However, under the semi-arid climate, the moisture supply is not sufficient to support this potentially higher production and crops burn off quickly when a dry period arrives. Thus the soils with lime at the surface are regarded as "droughty" soils.

The satisfactory topsoil structure of the Group A soils has not deteriorated significantly after many years of cropping. However where wind erosion has occurred hard patches have formed by the bombarding action of saltating sand grains. The amounts of drift produced are small.

Sandy loams of Group B are widespread on the upper slopes of hummocks and ridges and less common on the lower slopes and on plains. They have an abrupt texture change to sandy clay or sandy clay loam subsoils at a depth ranging from about 6 to 15 inches. The textural boundary is generally flat but it can be weakly irregular or strongly domed.

The colour of the A, horizon ranges from red-brown to yellowish brown whilst the B horizons range from reddish yellow to red. There is usually a bleached horizon above the textural boundary.

Lime is confined to the B horizon, with a zone of maximum accumulation beginning several inches below the textural boundary. The lime in this zone averaged 39 per cent of the field sample in the five profiles analysed. It occurs as a mixture of fine earth material and angular stones or nodules.

The pH of the A horizon varies from acid to alkaline whilst the subsoils are invariably highly alkaline. The most acid soil analysed had a pH of 6-4 at the surface and 5 - 2 in the A. horizon. This profile occurs on an interdune plain in the Parish of Timberoo, to the south-west of Ouyen. Further investigations are required to determine the extent of these acid profiles.

The following profile occurs on the upper slope of a ridge, beneath mallee vegetation in the Parish of Boigbeat to the south-east of Sea Lake.

0-1½ inches	yellowish-brown (5 YR 5/6) sandy loam, weak platy, brittle when dry, merging into
11-5 inches	yellowish-brown (5 YR 4/6) sandy loam, weak subangular blocky, soft, merging into
5-6 inches	reddish-yellow (5 YR 6/8) sand, apedal, firm when dry, abrupt change with level boundary to

6-18 inches	red (2.5 YR 4/8) sandy clay, weak subangular blocky, compact when moist hard when dry, occasional flecks of lime, diffuse change to
18-60 inches	mottled-red (2-5 YR 4/6) and reddish-yellow (5 YR 7/6) sandy clay, compact, lime abundant as fine earth material.

The sandy loams of Group B are widely cropped and field observation suggests that their agronomic features are similar to those of the Group A soils. However there has been no systematic comparison of the yields of crops and pastures on the two groups. Laboratory analyses suggest that, of the two, the Group B soils have lower fertility reserves, as indicated by the lower values for nitrogen and potassium in their A horizons. The significance of the acid A horizons in some of the Group B profiles requires investigation. In particular the pH may have a bearing on the choice of the most suitable type of annual legume. An early strain 'of subterranean clover *(Trifolium subterraneum)* may be better suited to the soils with acid A horizons than the medics *(Medicago spp.)* which perform best on alkaline soils.

The presence of the bleached A. horizon indicates that the penetration of moisture is retarded at the sharp textural boundary. However, it is likely that moisture penetrates to a depth similar to that in the Group A soils, because of the similar over-all texture.

Sandy loams of Group C occur to a limited extent, mainly on plains and on lunettes. The A horizons are shallow, generally less than six inches thick, and they give way abruptly to clay B horizons so that the over-all texture of the profiles is relatively heavy. Topsoils range from red-brown to yellowish-brown whilst the B horizons are red. There is frequently a bleached A_2 horizon which, in the southern part of the region, may contain ironstone concretions. The textural boundary is level. In contrast with other soils in north-western Victoria the structure of subsoils is well developed ' being strong angular blocky and also prismatic. The soils are usually relatively low in lime which is confined to the lower part of the B horizon, mainly as fine earth. Subsoils frequently contain salt and gypsum. The profiles analysed were alkaline at the surface and highly alkaline at depth. The following profile occurs on a grassland plain in the Parish of Benetook to the west of Red Cliffs.

0-3 inches	yellowish-brown (5 YR 5/8) fine sandy loam, weak subangular blocky, firm, abrupt change to
3-9 inches	red (2.5 YR 4/6) clay, strong angular blocky and moderate prismatic, peds hard when dry, diffuse change to
9-36 inches	reddish-yellow (5 YR 6/8) clay, moderate angular blocky and weak prismatic, lime present as coatings to peds, diffuse change to
36-60 inches	reddish-yellow (5 YR 6/6) clay, lime, salt and gypsum present.

The soils are of moderate fertility but their moisture characteristics are less favourable than those of Groups A and B. Because of the high field capacity and low permeability of the clay B horizons, moisture penetrates only to a shallow depth, and a relatively high proportion of moisture is lost by evaporation. This problem becomes more acute as the A horizons become thinner.

Wind erosion leads to the exposure of the clay B horizons which, because of their high salt contents, develop problems of dry land salting (see chapter on Hopetoun. land system). The A_2 horizon is hard when dry and relatively resistant to further breakdown and it sometimes remains, usually as slightly raised patches.

Shallow sandy loams on limestone occur on plains, hummocks and ridges, mainly in the western parts of the Central Mallee and Millewa land systems. They consist of a shallow layer of soil overlying a dense layer of limestone which, in its upper parts consists mainly of stones but also of sheet limestone (Plate 8). Below this solid capping fine earth lime predominates. Before the land is cleared the surface is littered with stones which, however, become more dense following cultivation (Plate 9).

The shallow soil has similar properties to the surface of Group A soils. It is alkaline and ranges in colour from red-brown, yellowish brown to grey-brown. In addition there are usually patches of duller soils in which fine earth lime reaches the surface. The following profile occurs beneath mallee vegetation on a plain to the east of Murrayville:

0-1½ inches	yellowish-brown (5 YR 5/8) sandy loam, moderate platy, brittle when dry, stones present, abrupt change to
1½-3 inches	red (2.5 YR 5/8).sandy clay loam, weak platy, soft, stones present, abrupt change to
3-60 inches	impenetrable limestone underlain by material in which fine earth lime predominates.

The soils are of moderate fertility. Although frequently cropped they are not well suited to cultivation because of the excessive wear and tear on machinery caused by the dense litter of limestone. The stones protect the soil from the wind so that the erosion hazard is low. Annual pastures make satisfactory growth.

The satisfactory growth of crops and pastures suggests that plant roots are able to penetrate the dense limestone. Although this layer has a low moisture storage capacity the loss of moisture beyond the root zone of plants by deep percolation appears to be limited under the semi-arid climate. This loss may be serious only in years of higher-than-average rainfall.

Plate 8 – Limestone deposits in the form of sheet and rubble, between Murrayville and Danyo in the Central Mallee land system.

Plate 9 – Outcrop of shallow sandy loams on limestone, on a plain tot he west of Tutye, in the Central Mallee land svstem.

Light Clays Although light clays occur in most land systems they are most widespread in the south-eastern parts of the region, on plains and on the lower slopes of hummocks and ridges. The profiles are of clay texture throughout except for shallow A, horizons of light clay or clay loam.

The light clays are usually gilgaied. The most common microrelief consists of rounded to oblong depressions, or shelves, alternating with raised areas, or puffs (Plate 23). Occasionally there are elongated puffs separated by more or less level shelves. With repeated cultivation the difference in level between puffs and shelves diminishes and it is generally about one foot or less. However, under timber, differences in level as great as three to four feet have been observed.

The colour of the soils varies with microrelief. The A. horizon is generally red-brown to brown on the puffs and grey-brown to grey in the shelves. Subsoils show less variation, ranging from yellowish-red through reddish-yellow to yellowish-brown and they frequently contain grey and brown mottles.

Both the puffs and shelves have a relatively high lime content at the surface. The amount in the shelves shows little change with depth whereas in the puffs there is a large increase at shallow depth. Even on the puffs, however, the lime content at depth is generally less than that in the subsoils of Groups A and B.

Irrespective of microrelief the soils are alkaline at the surface and highly alkaline in subsoils. The following puff and shelf profiles occur on aa pplain beneath mallee vegetation in the Parish of Carina near Panitya.

Puff profile.

0-2 inches	reddish-brown (5 YR 4/3) light clay, weak subangular blocky, friable, merging into
2-24 inches	lighter reddish-brown (5 YR 5/4) clay, moderate subangular blocky and weak prismatic, friable, lime present as coatings to peds, diffuse change to
24-60 inches	mottled red-brown, brown and grey clay, lime present as flecks.

Shelf profile.

0-3 inches	dark-grey (10 YR 4/1) clay, moderate subangular blocky, friable, merging into
3-36 inches	grey (10 YR 511) clay, strong subangular blocky and weak prismatic, friable, lime present as occasional flecks, diffuse change to
36-60 inches	mottled grey-brown, red-brown and brown clay, lime present as occasional flecks.

Among the more widespread soils of the region the light clays are the most fertile as indicated by their relatively high levels of nitrogen, exchangeable metal cations and potassium. The puffs, however, have a dry land salting hazard as indicated by the high chloride contents close to the surface. In addition the high subsoil chloride contents both on puffs and shelves indicate that there is a salinity hazard should the soils become saturated by seepage from higher land.

Under the prevailing climate the light clays have unfavourable moisture characteristics and their performance under crops and pastures varies widely from the moister to the drier parts of the region. Moisture penetrates to a relatively shallow depth. The erosion hazard is slight and where the soils have been intensively cropped for many years the topsoil structure has generally remained satisfactory.

Heavy Clays The heavy clays are confined to periodically flooded sites in the Tyrrell , Lindsay Island -and Wycheproof land systems. They are grey, coarsely structured soils of heavy clay texture throughout. Many of their chemical features, including pH, are variable because of a great variation in the frequency of flooding. may be present, throughout the profile or absent. The levels of chloride in subsoils are generally low.

The following profile occurs on a lake bed in the Parish of Wilhelmina to the north of Hopetoun:

0-8 inches	dark-grey (2.5 Y 4/0) clay, strong 8 in. prismatic, hard when dry, lime occasional as nodules, diffuse change to
8-19 inches	grey (2-5 Y 60/) clay, strong 8 in. prismatic, hard when dry, lime present as nodules and soft pockets, diffuse change to
19-60 inches	grey (2-5 Y 6/0) clay, moderate subangular blocky, lime present as nodules and soft pockets.

Although fertile, the soils are heavy and thus they have poor moisture characteristics. This renders them unsatisfactory for crop and pasture growth, except perhaps following a flood.

Saline Soils These are soils in which the salt content is high enough to exclude native vegetation other than halophytes. They are confined to the Raak land system which occurs in internal drainage basins. Two kinds of soil can be recognized according to the distribution of salt in the profiles.

Soils which are saline to the surface are commonly dull red, finely textured, apedal and soft, with copi at variable depth. The dominant native vegetation is samphire *(Arthrocnemum halocnemoides).*

Soils which are non-saline at the surface but saline at depth have sandy surfaces of variable depth and their predominant native vegetation is bladder saltbush *(Atriplex vesicaria).*