THE SOILS OF THE HAMILTON PASTORAL RESEARCH STATION, VICTORIA

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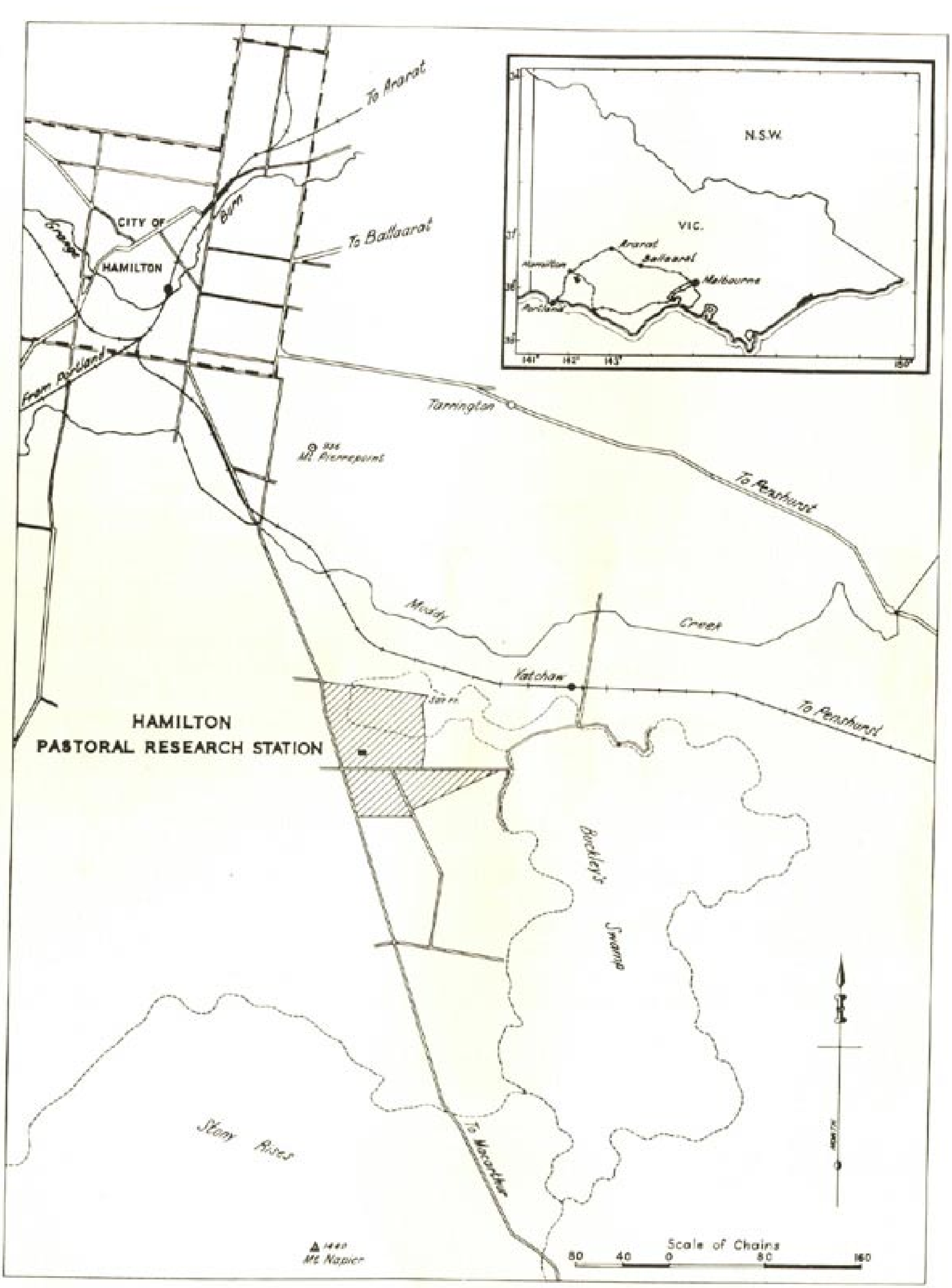

INTRODUCTION

The Hamilton Pastoral Research Station of the Department of Agriculture covers 844 acres, and lies 6 miles south-east of Hamilton, on the Mount Napier Road, in the Parish of Monivae, County Normanby Victoria (see Fig. 1). It is due west from Melbourne, approximately 200 miles by rail via Ballarat.

The Research Station was established in 1959 on former freehold pastoral land purchased by the Crown for the present purpose, and serves as a district centre for the experimental work of the Department, in animal husbandry, pasture and soil management, fertility and general agricultural studies.

At the time of the survey in June 1961, the Research Station carried about 1900 sheep including lambs, mainly on subterranean clover - rye grass pasture, and 25 head of beef cattle.

The purpose of the survey is to provide a frame work of reference within which to plan and evaluate the experimental work of the Research Station. Within the context of other broader-scale studies it should serve also as a detailed "sample survey" of the soils of the district. As the quantitative significance of particular soil factors becomes better established, the present survey should help in relating Research Station and district experience to one another, and contribute to the understanding of each.

THE ENVIRONMENT

History

When Mitchell first explored the Western District in 1836, his reports were so glowing that the Henty family, and others from Portland and van Dieman's Land quickly brought in their flocks; first into the more open country near the confluence of the Wannon and Glenelg Rivers, and soon afterwards into the neighbourhood of Grange Burn. They were joined thereabouts by other squatters coming south and west from the Murrumbidgee country, and from the Port Phillip settlements.

The Wedge Brothers received a licence for the "Grange Creek" area, (now Hamilton) in 1838. Two years later this was brought by Captain Lonsdale, who quickly occupied the neighbouring country. Monivae Station of about 27 square miles, which includes the site of the Research Station, was one of several properties occupied from about 1841, though occupancy was not licenced until 7 years later.

In 1853 the Wannon – Glenelg country was reported to have been "covered with grass like a land marsh", probably dominated by kangaroo grass (*Themeda australis*). The area about Monivae appears to have carried a shrub woodland of swamp gum (*Eucalyptus ovata*), blackwood (*Acacia melanoxylon*), lightwood (*A. implexa*) and banksia until about 1870. However, stocking was heavy throughout the district from the earliest days, and there was a rapid and general deterioration of pastures, and invasion by inferior species. "Silk grass" and hillside erosion are especially mentioned by Robertson at Wannon in 1853 (Kiddle 1961). Robertson incidentally reported the surprising number of 37 grasses being displaced by "silk grass".

The district was on the main overland route to South Australia and an important pastoral centre in its own right. As there was no railway until 1878, oats and hay for horse and bullock teams were important crops. Wheat was grown for a few years following the gold rush to central Victoria in the early 1850's, but disappeared as wheat growing developed in the Wimmera. Throughout its history, the district has been noted chiefly for the grazing of sheep for wool and to a less extent of dairy and beef cattle, on volunteer pastures.

At the land auctions of the late 1860's, a large part of Monivae Station was secured to one ownership, and properties remained large until well into the present century. The volunteer pastures were valued for their production of fine wool, and there was no early adoption of pasture improvement in the modern sense. However, superphosphate as a fertilizer has been used in increasing amounts in the

Hamilton district since the late 1920's. At present dressings average about one hundred weight per acre on two million acres of pasture in the Glenelg Region.

Sown pastures have increased since 1954 and amount to more than half of the total pasture area (Anon. 1910). There is no evidence of the use of fertilizers or sown pastures on the Research Station site before 1937.

The general draining of Buckley's Swamp and the flats of the Research Station has gone on over many years. Occasional oat and hay crops have been taken off, but for most of the time this lower ground has provided only rough grazing, with white tussock grass (Poa caespitosa) predominating.

The above historical and local data are based on "Men of Yesterday" by Margaret Kiddle, "Pastures New" by Billis and Kenyon, and the Resources Survey of the Glenelg Region.

Geology and Physiography

The Hamilton district, including the Research Station, occupies part of the Western District basalt plain. It is a fairly maturely eroded part, of rolling country with well-defined drainage ways and few surface rock outcrops. It contrasts sharply with the very immature Stony Rises about Mount Napier, Mount Rouse and Mount Eccles, and with the gently undulating, lake dotted treeless plain farther east.

The last of the major lava flows in the Research Station area is classes broadly as one of the older of the Newer Basalts, of early Pleistocene age. One apparent centre of origin is near Buckley's Swamp school 2 miles south of the Research Station. However exposures in a drain show both the older basalt and the much newer flow from Mount Napier to underlie the Swamp itself.

A Mines Department bore on high ground near the front gate of the Research Station records 20 feet of clay and rotton rock, then 310 feet of basalt over fossiliferous marine sand and marls.

These underlying materials compare with the Lower Pliocene and Miocene exposures at Clifton, west of Hamilton, where Muddy Creek and other streams have broken through the basalt.

Climate

The climate combined with the geology of the region has produced the landscape and soils, and through them the pattern of plant growth. The climate is mild and moist enough to give a long growing season, dry and warm enough in summer to mature oats for grain and to make hay readily, and reliable enough to make severe droughts a rarity.

The elements of climate change but little over the western basalt plains, and the Research Station is near enough to Hamilton in position and elevation to suppose that their climates will be the same. They are well placed to typify the climate in the country between Dunkeld, Hawkesdale and Casterton.

Hamilton records (Table 1) are therefore the basis for the following paragraphs, extracted from "Resources Survey of the Glenelg Region" (Anon. 1960). In this there is a detailed discussion, especially of monthly and seasonal rainfall probabilities.

Table 1: Climatic Data for Hamilton (615 ft)

Element	Jan	Feb	Mar	Apr	May	Jne	Jly	Aug	Sep	Oct	Nov	Dec	Year
Temperature													
Av. Max ^{o}F.	77	79	74	66	60	55	54	56	59	65	69	74	66^{o}F
Av. Min. ^{o}F.	51	52	50	46	43	40	39	40	42	44	46	49	45^{o}F
min. temp. is :													
(i) below 32^{o}F.				0.2	1.5	3.5	4.0	1.7	1.5	0.6	0.4		13.4
(ii) 32-36^{o}F.	0.1	0.2	0.3	1.3	2.4	4.7	5.4	4.2	2.2	3.2	1.2	0.6	25.8
Rainfall													
Average pts.	110	145	143	214	264	265	277	306	300	248	199	194	2665
p.e. * %	19	26	48	87	98	100	100	99	100	89	64	44	

* p.e. is the percentage chance of receiving rainfall equal to or greater than the "effective" amount, P, where $P= 0.54E^{0.7}$ and E is the evaporation in inches from an Australian Standard Tank. E has been estimate from the saturation deficit at 9 a.m. and percentage cloudiness (Anon. 1960). P is intended to represent the minimum precipitation necessary to start and maintain pasture growth.

Hamilton has $26^1/_2$ in. average annual rainfall with a pronounced maximum in July, August and September. There are an average of 39 frosts per year, 23 in June, July and August, the average first and last dates being April 6th and November 16th. The temperature rises above 100 ^{o}F on no more than 2 to 4 days per year.

Sunshine and evaporation can be estimated only roughly at 2400 hours of sunshine per year and 40 in. evaporation. The probability of receiving "effective" rain in any one month rises steeply with the opening rains in April, and remains high at 90 to100% throughout winter and spring, dropping sharply again in November. This produces a "growing season" of 8 constructive months from April to November in each of which this probability is 50% or more.

The reliability of the dry period which normally occurs each summer is indicated by figures for Casterton, quoted in the Resources Survey. There is an 18% chance of a 5 month dry period beginning with November, in each month of which the rainfall will be below the effective amount, but a 41% chance of a 4 month "dry" beginning with December.

THE SOILS

Soils and Landscape

The pattern of soils on the Research Station is quite simply related to the landscape. Considering first the colour of the clay in the B. horizon, this is yellowish brown mottled with reddish brown on the hill crests and main slopes, yellow-grey on lower concave slopes of restricted drainage, and black on low, flat, swampy areas.

Monivae gravelly loam with some Monivae loam occupies the rather flat-topped ridge in the Main Trial and Quarry paddocks. Slightly lower rises carry Monivae loam chiefly.

These two Monivae soils have grey-brown surfaces which often appear brown or red-brown after exposure in road-cuttings. Much of the surface has been stripped from Monivae gravelly loam for road making, leaving an uneven surface with clay subsoil exposed in many places.

The main slopes, below the Monivae series, carry the grey or brownish grey surface soil of Normanby silty loam. This usually has less buckshot gravel than Monivae loam. Basalt rock outcrops occasionally.

Normanby silty loam on the Research Station occurs on gentle to moderate slopes. On convex slopes it runs down to join the black clay soils of the flat, but elsewhere on lower, concave gentle slopes Yatchaw clay loam intervenes.

Relationship to District Soils

Four of the six soil types recorded on the Research Station are probably extensive in the district. These types are Monivae loam and gravelly loam, Normanby silty loam, and Yatchaw clay loam.

The Monivae series and Normanby loam have been recorded as components of the "Monivae Land Unit", in a broad-scale survey of the country south and west of the Grampians (Gibbons and Downes, in press). These three soil types, together with Yatchaw clay loam, probably are typical of this land unit, which occupies a large area of rolling country south of Muddy Creek. It is formed on older Pleistocene basalt which has not been dissected through to earlier sediments.

A fifth soil type, Buckley clay, doubtless occurs elsewhere in the region. However, it is not typical of the main swamp areas such as Condah Swamp and most of Buckley's Swamp. These carry peaty soils not found on the Research Station itself.

Classification

The Research Station falls well within the region of Podzolic Soils in the Soil Map of Australia (Stephens 1961). From the descriptions given in the Manual of Australian Soils (Stephens 1962) the dominant soil, Normanby silty loam, and the Monivae series are Grey Brown Podzolics, although the Monivae series show some features of Lateritic Podzolics in the surface ferruginous gravel and the slight light grey mottling in the BC horizons.

By the same set of criteria Yatchaw clay loam probably is nearer to a Prairie Soil than to a Grey Brown Podzolic, and Buckley clay and Type A are Wiesenbodens.

Northcote's mapping unit (Ral) for this area in Sheet 1 of his Atlas of Australian Soils (Northcote 1960) contains dominantly hard-setting loamy soils with brown, and brown mottled clayey subsoil, unbleached A_2 horizons, a neutral reaction trend, and frequent ironstone gravel. Associated with these are closely related soils with yellower subsoils, and some cracking grey clays. Minor soils include some which remain evidence of surface structure when dry, i.e. are "non-hard-setting", and there are also deep cracking clays in the stream valleys.

The soils found on the Research Station, and described below, agree in general with the above arrangement, except that the B_1 horizon clay colours fall more often in the "y" than "b" range Northcote defines (1960b). This is true of both the Monivae series, which retain evidence of surface structure when dry, and the Normanby silty loam, with hard-setting surface and mottled B_1 horizon.

Yatchaw clay loam whose B_1 horizon usually is not mottled is definitely in the "y" subdivision, while Type A with the top of the B horizon dark and dominantly grey is in the "dark clay" subdivision.

Buckley clay agrees with Northcote's classification of some soils in the stream valleys – a texturally undifferentiated deep, dark grey clay, with seasonal cracking, smooth faced peds throughout, and rocks below 60 in.

More specifically in terms of Northcote's coding of Profile Forms, Monivae gravelly loam and Monivae loam are Dy5.22 soils, but near to Db3 and Db4. Normanby silty loam is Dy3.22, Yatchaw clay loam is Dy2.22, Type A is Ddl.1 "hard setting" in the dry season or Dd3.13 if it retains evidence of structure. Buckley clay is Ug5.16.

Areas of the Soil Types

The 844 acres of the Research Station are made up as follows:-

Normanby silty loam (including 1 acre of rock outcrop)	341	acres or	40%	less $7^{1}/_{2}$ ac.
Buckley clay	261	" "	26%	" $4^{1}/_{2}$ ".
Yatchaw clay loam	163	" "	19%	" $2^{1}/_{2}$ ".
Monivae loam	49	" "	6%)	) " 9 ".
Monivae gravelly loam	42	" "	5%)	
Type A	34	" "	4%	" 1 ".

Structures such as buildings, yards, roads, drains, plantations, etc., as shown on the Soil Map, reduce the areas available for agricultural purposes by the amounts of the last column.

Descriptions of Soil Types

The profile descriptions that follow represent each soil type. The average characteristics are given, with some indication of the range occurring within the soil type.

MONIVAE GRAVELLY LOAM The gravelly hill crest soil.

A_1 0-5 in. Very dark grey-brown clay loam or loam; much small and large ferruginous gravel and some rock fragments; strongly structured, crumbly and porous; high in organic matter; sharp boundary with:

A_2 4-16 in. Grey-brown clay loam; gravel, stone structure, and consistence as above; passing at depths varying from 10 to 20 in. to:

B_1 16-24 in. Yellowish brown medium or heavy clay; scattered soft rock and sometimes ferruginous gravel; moderate structure; passing gradually at 20 to 30 in. to:

B_2 24-40 in. Brown and brownish red, strongly mottled heavy clay; slight soft red inclusions; passing at 30 to 48 in. to:

C 40-48 + in. Brown, brownish red and light grey, strongly mottled heavy clay with decreasing soft inclusions; sometimes with soft rock increasing with depth.

MONIVAE LOAM The grey-brown hill-top soil.

A_1 0-5 in. Dark grey-brown (7.5 YR 3/2) loam; trace of small ferruginous gravel; porous and crumbly; sharp boundary with:

A_2 5-10 in. Grey-brown clay loam; moderate small gravel; crumbly becoming denser and weaker structured with depth; passing to:

A_2B_1 10-14 in. Yellowish grey-brown light clay; slight to moderate gravel; passing to:

B_1 14-24 in. Brown with yellow-grey, diffusely mottled light or medium clay; moderate structure ($^{3}/_{4}$" peds); passing to:

B_2 24-42 in. Brown with brownish red, mottled medium or heavy clay; some soft red (10R) inclusions; diffuse boundary with:

C 42-72 + in. Brown with brownish red and very light grey, strongly mottled heavy clay; becoming increasingly tough and plastic (moist) with depth; often with soft rock fragments from below 48 in.

NORMANBY SILTY LOAM The brownish grey soil of the main slopes.

A_1 0-5 in. Dark brownish grey (10 YR 3/2) silty loam or loam; sharp boundary with:

A_2 5-13 in. Yellowish brownish grey (2.5Y 5/2) silty loam; slight or moderate small ferruginous gravel; passing gradually to:

A_2B 13-19 in. Grey or yellowish grey, clay loam or light clay; slight or moderate small ferruginous gravel; gradual boundary with:

B 19-40 in. Yellowish brown with red-brown (or sometimes yellow-grey), diffusely mottled medium clay; often with brownish red soft inclusions; moderate structure; passing very gradually at 36 to 48 in. to:

C 40-60 + in. Brownish red and light grey, strongly mottled medium clay; moderate structure; often with brownish red soft inclusions; sometimes very tough and plastic (moist).

YATCHAW CLAY LOAM Poorly drained; on gentle, concave lower slopes.

A_1 0-5 in. Dark brownish grey or dark grey (10YR 3/2 or 3/1) silty clay loam; sometimes with slight gravel; compact and weakly structured; gradual boundary with:

A_2 5-13 in. Brownish grey or grey clay loam with or without slight gravel; gradual boundary with:

A_2B 13-18 in. Similar light clay; slight gravel; diffuse boundary at 12 to 22 in. with:

B 18-26 in. Yellowish grey to yellow-brown with dark dull mottings, medium or heavy clay; sometimes with slight ferruginous gravel in the upper part; passing gradually to:

BC 26-48 + in. Heavy clay, ranging from
(a) yellowish grey, with pockets of lime after 48 in.
(b) brown and red-brown mottled with light grey.

This unit as mapped contains a rather large proportion of soils marginal to Normanby silty loam and Type A, together with variability due to colluvial gravel, and to shallow and deep surfaces of possible incipient gilgaies.

BUCKLEY CLAY The "black" heavy clay soil of the main swamp.

A 0-5 in. Very dark grey ("black") (10YR 2/1) heavy clay; weak or moderate structure; passing gradually at 2 to 8 in. to:

BC 5-72 in. Very dark grey ("black") heavy clay; very weak structure, very tough when moist or wet; becoming gradually lighter in colour and yellower at depths below 20 to 60 in.; diffuse boundary with:

72-90 in. Greyish yellowish brown and grey, moderately mottled medium clay; soft and unchanged rock fragments increasing with depth:

90 in. Basalt rock.

TYPE A A "black" light clay soil; in high level depressions and on the margins of the main flat.

A 0-5 in. Very dark grey ("black") (10YR 2/1) light clay or silty clay loam; gradual boundary with:

B 5-16 in. Dark grey with brown root channels, medium or heavy clay; diffuse boundary at 8 to 24 in. with:

16-48 in. Grey with yellowish grey, diffusely mottled medium or heavy clay; very weak structure; very tough when moist; yellow-grey increasing below 30 in. sometimes with pockets of fine sandy clay loam or a trace of lime.

PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS

Field and laboratory data for single representative profiles taken from each of the six types are given in Appendix III. These data are discussed briefly in the following paragraphs.

In addition, the results of a more general survey of the surface soils over the research Station are considered in regard to available potassium, phosphorus, organic matter, chlorides and pH.

Analytical methods are given in Appendix II.

Texture and Particle Size

The soils of the Research Station are composed mainly of fine textured material. Except in those horizons where there are large amounts of concretionary iron, ("buckshot" gravel) there is very little coarse sand (1-2%). Fine sand exceeds silt in the A horizons but, in most cases, is roughly equal to it in the B and deeper horizons. The clay contents of the B_1 horizons are high or very high in every case (51 to 83%), and remain high to a depth of more than 7 ft in most of the soil types.

The soils all have fairly deep surface horizons (10 to 20 in.) except Buckley clay and Type A. Textural differences are greatly influenced by iron concretions. There is so little coarse sand the gravel is clearly distinct from the rest of the material. If the gravel is excluded, the surface material has only a narrow range of textures, viz., from loam to light clay loam, with clay contents ranging from 15 to 31% and silt plus clay varying only slightly on each side of 50%.

Moving down the slope, both gravel and coarse sand are concentrated deeper in the profile. Thus the main occurrence is in the A_1 horizon of Monivae gravelly loam, in the A_2 horizon of Monivae loam, and in the AB horizons of Normanby silty loam and Yatchaw clay loam.

Soft red inclusions are common in the deep subsoils of the three higher soil types, but only in the Normanby silty loam reference profile are they hard enough to record as gravel (17% of the field sample at 38 to 48 in.). The horizon is underlain by very tough clay with very pale grey mottling.

Considering the particle size distribution throughout the profile, the data presented clearly set the Monivae series and Buckley clay apart from the other soil types, and also show that Normanby silty loam, Yatchaw clay loam and Type A have very similar particle size distributions.

Soluble Salts

Both total soluble salts, and chloride ion concentrations are generally low. Only in the reference profiles of the two swamp soils are the soluble salts above 0.10% (calculated from electrical conductivity). In the Type A profile there is 0.22% at 29 in., and in the Buckley clay profile 0.15% at 27 in., rising to 0.21% at 42 in. All surface concentrations are very low.

These are spot values, the actual concentrations probably varying widely from point to point and from one season to another. However, the generally low figures are confirmed by numerous chloride ion determinations. These were made at two depths in the subsoil at 29 sites, and in 13 composite surface samples, each of 50 cores, 0-4 in. depth. They show that while all the concentrations are low, the swamp soils do contain slightly more chloride than the others, and that there is very little variation amongst the four higher soils.

The Monivae series, Normanby silty loam and Yatchaw clay loam together had 0.013% and Buckley clay 0.019% sodium chloride in the surface (50 sites each). Taken together these two types showed 0.034% in the 2^{nd} foot and 0.090% in the 4^{th} foot (5 sites at each depth).

The low total soluble salt content of all the surface soils, and of the profiles to 3 ft or more in the hill soils indicates leaching in these soils to lower depths. However, the soils are saved from chemical poverty by the moderate concentrations of exchangeable cations, discussed in a later section.

pH

All the reference profiles show a consistent trend of pH increasing with depth. All the surface soils are moderately acid (pH 5.6 – 6.1) and the B_1 horizons are slightly acid (pH 6.3-6.7). Deeper horizons vary from a slightly acid to strongly alkaline (pH 6.6 – 8.7).

The Monivae loam and Normanby silty loam profiles are acid to beyond 6 ft, but pH values above 8.0 occur in the profiles of Yatchaw clay loam at 52 in. and in Type A at 29 in. The Buckley clay profile has pH values of 7.6 to 7.9 from 27 to 80 in.

The slight differences in surface pH between the soil types shown by the reference profiles may not be significant. The values for the 50-core composite surface samples are more reliable and are given in Table 2. These data suggest that the Monivae series is more variable, but also very slightly more acid in the surface than Normanby silty loam and Yatchaw clay loam, while the two swamp soils are very slightly less acid.

Potassium, Nitrogen, Organic Carbon and Phosphorus in Surface Soils

Some chemical analyses of 15 surface samples are presented in Table 2. Each sample is a composite of 50 one inch diameter cores, 4 in. deep, taken at random from one soil type as mapped in one paddock, except that Monivae loam and Monivae gravelly loam were sampled as one unit.

The analyses appear to show trends from one soil type to another. However, these trends must be accepted with caution since the data do not indicate the magnitude of the sampling errors involved.

The Tip, South Quarry, and Main Trial paddocks offer the best comparison for the three main soil types, since these paddocks are all of comparable size and the three soil types were sampled in each. Data from the other paddocks can be compared with the range of values in the three main ones. The Species Trial is not very significant as the paddock is so small and the two types are not well defined there.

Potassium. – The soil potassium as estimated here is commonly referred to as available potassium. It represents a large part of the exchangeable potassium. The relationship has been established for these soils, and available potassium (x p.p.m) in the composited surface soils, except Buckley clay, may be converted to exchangeable potassium (y p.p.m) using the regression $y = -0.5 + 1.21x$. The A_1 and A_2 horizons both fit this regression line, but the surface of Buckley clay and the subsoil horizons do not. The regression established for the B_1 horizons and acid deeper horizons is $y = 12.9 + 1.50 x$.

The figures for the three main paddocks indicate that available potassium is higher in the Monivae series than in the Normanby silty loam, and is lowest in Yatchaw clay loam. The one figure for Type A is comparable with the mean for Yatchaw clay loam. However, the one figure for Buckley clay shows this soil to have the highest inherent level of available potassium of all the soil types.

Table 2: - Chemical Properties of Surface Soils

Soil Type	Paddock						
	Tip	South Quarry	Main Trial	Av.*	North Quarry	Species Trials	Brown's

	Potassium p.p.m						
Monivae series	177	220	152	183			
Normanby silty loam	139	105	132	125	144	184	158
Yatchaw clay loam	90	71	128	96		182	
Type A	108						
Buckley clay							295
	Nitrogen %						
Monivae series	0.40	0.37	0.32	0.36			
Normanby silty loam	0.36	0.26	0.27	0.30	0.28	0.21	0.31
Yatchaw clay loam	0.30	0.24	0.26	0.27		0.22	
Type A	0.37						
Buckley clay							0.34
	Organic Carbon %						
Monivae series	5.3	4.8	4.2				
Normanby silty loam	4.9	3.7	3.7		3.8	2.8	4.1
Yatchaw clay loam	4.0	3.1	3.6			3.2	
Type A	4.5						
Buckley clay							4.4
	Phosphorus p.p.m.						
Monivae series	34	19	19				
Normanby silty loam	22	12	19		15	26	26
Yatchaw clay loam	21	13	27			20	
Type A	31						
Buckley clay							9
	pH						
Monivae series	5.4	5.3	5.7				
Normanby silty loam	5.6	5.6	5.7		5.7	5.6	5.5
Yatchaw clay loam	5.6	5.7	5.7			5.6	
Type A	5.8						
Buckley clay							6.0

* Average Tip, South Quarry and Main Trial paddocks.

Some of the values found indicate a deficiency of potassium for pastures, and draw attention to the need for potash in fertilizer programmes on the Research Station. The deficient levels are in Yatchaw clay loam, Type A, and in Normanby silty loam in the South Quarry paddock. Normanby silty loam has marginal levels elsewhere and this soil type, therefore, should be watched in regard to future need for potash.

The high levels of available and exchangeable potassium in Buckley clay indicate that it will not require potash to maintain pastures. Also, moderate reserves in the Monivae series should be adequate for some time.

Nitrogen. – Generally, total nitrogen levels are high in all the surface soils. Total nitrogen in the three main paddocks is higher in the Monivae series than in Normanby silty loam and apparently lowest in Yatchaw clay loam. Figures for the other three paddocks agree.

Buckley clay and Type A have high total nitrogen contents comparable with those in the Monivae series. These do not reflect high productivity or the establishment of clover in these black clay soils, but rather conditions of waterlogging and poor aeration in the past, which have favoured the accumulation of organic matter by restricting microbial decomposition.

Organic Carbon. – The organic matter contents (organic carbon x 1.72) of the surface soils are all fairly high, the range found being 4.8 to 9.1% in the composite samples.

The carbon-nitrogen ratio varies only slightly over the research Station, indicating only slight or no differences in the nature of the organic matter. Values of 12.2 and 12.9 were found in the two swamp soils, but the ratio may be slightly higher in the other soil types, as the 13 situations have values ranging from 12.9 to 14.5.

Phosphorus. – The phosphorus reported in Table 2 represents a small but relatively available fraction of the total soil phosphorus.

In at least two situations, the levels of available phosphorus are moderately high, while in nine other they are fairly good. These rather good levels are attributed to residual phosphorus rather than to native phosphorus, although the latter cannot be assessed from the data and may vary slightly between the soil types. All that can be said in regard to native phosphorus is that it is only slightly below 9 p.p.m in Buckley clay and is possibly highest in the Monivae soils.

The total amounts of superphosphate that have been used in the Tip, Main Trial, Species Trials, and Normanby silty loam part of Brown's paddocks are said to have been approximately the same viz., $8^1/_2$-10 cwt/ac. The soil analyses are consistent in that samples from these four paddocks show roughly the same phosphorus contents, although there are differences within the paddocks which suggest that certain parts may have received preferential topdressing. These parts are the Monivae series and Type A in the Tip paddock, and the Yatchaw clay loam in the Main Trial paddock. The low phosphorus content of the Buckley clay sample is consistent with the small amount of topdressing on that soil type.

The greatest amount of superphosphate is said to have been used in the North and South Quarry paddocks, 17-19 cwt/ac. The analyses do not confirm this; in fact they suggest less superphosphate than in the other four paddocks.

Exchangeable Cations

The cation data presented in Appendix III include the individual cations, calcium, magnesium, potassium, sodium, and hydrogen, expressed both as total amounts per 100g of soil and as percentages of the cation exchange capacity. The exchange capacity of the soil is also given per 100g of clay for those B_1 and deeper horizons in which organic matter is virtually absent.

The overall picture is that the cation exchange capacity of the soil is moderate in both surface and subsoil horizons, except in Buckley clay where it is fairly high. Lower values occur in the A_2 horizons than in the corresponding A_1 horizons because of less organic matter; whereas high clay contents are mainly responsible for the moderate values found in the B_1 and deeper horizons, except that organic matter may contribute significantly in Buckley clay.

The exchange capacity of the clay is an indication of the kind of clay minerals present. The values range widely from 29 to 79 m.e. % and show trends sufficiently definite to indicate that there are some differences in the constitution of the clay in the different soil types. The exchange capacities of the Monivae loam and Normanby silty loam clays are consistent with mixed kaolinite and illite minerals, such as have been recorded in soils on basalt at Mortlake and elsewhere in the Western District (Anon. 1957). However, it is evident that moving downslope the cation exchange capacity of the B horizon clay increases progressively, passing through Normanby silty loam and Yatchaw clay loam to Buckley clay. In the last two soil types, the values are high enough to indicate that kaolinite must be a very minor component of the clay complex, and that illite is associated with clay minerals of higher exchange capacity, possibly montmorillonite. This is particularly so in the Buckley clay profile.

The exchange complex of the surface horizon in all the profiles is strongly dominated by hydrogen (41-61%), with calcium (21-35%) easily the dominant metal ion, except in the case of Buckley clay, where magnesium slightly exceeds calcium.

There is a marked and rather similar trend within each profile except in that of Buckley clay. The magnesium to calcium ratio rises steeply passing from the A to the B_1 horizon, then rises only slightly in the horizons below the B_1. For instance, in the Normanby silty loam profile, the ratio rises from 0.5

to 0.7 in the A_1 and A_2 horizons, respectively, 1.6 in the B_1 and 1.8 in the next horizon. The trend is very similar in the Yatchaw clay loam profile, but is slightly more pronounced in the Monivae loam profile. The Buckley clay profile differs in that the magnesium to calcium ratio rises gradually from the surface downwards.

Potassium is a very minor component of the exchange complex of all horizons examined. The proportion of exchangeable potassium varies from 1 to 3% in the A horizons and from slightly less to slightly more than 1% in the B and deeper horizons. It is remarkably constant throughout any one profile except that of Monivae loam.

Exchangeable sodium is also a minor component, the proportions being quite low in the A and B horizons. It decreases slightly with depth reaching 7% of the exchange capacity in the deep subsoils of the higher situated soil types, and 10% in the Buckley clay deep subsoil.

The actual amounts of exchangeable calcium, magnesium and potassium present are important as a source of plant nutrients. In this regard the data show that the surface soils are well supplied with calcium and magnesium, with somewhat lower levels in the A_2 horizons. The highest amounts of exchangeable calcium and magnesium occur at the highest amounts of exchangeable calcium and magnesium occur at the Buckley clay site, and the lowest at the Normanby silty loam site. However, there is no suggestion that these low values represent deficiency levels of calcium and magnesium for pastures. Also, there are no data to indicate whether or not the Normanby silty loam site is the average for that soil type.

Exchangeable potassium is low in the A_1 horizons of the Normanby silty loam and Yatchaw clay loam profiles and supports the probability, which was mentioned in the previous section, of potassium deficiency occurring in these two soil types. In the other profiles, exchangeable potassium is moderately high in the surface soils. (The exchangeable potassium figures may be compared with those for “available” potassium by converting to parts per million (m.e. x 390) and using the regression equations given in the previous section).

Agriculturally, interest lies in the subsurface and subsoil reserves of potassium available for pastures, and the date show that generally reserves are likely to be low or only moderate. Thus very low amounts of exchangeable potassium occur in the A_2 horizons, and only moderate amounts are present in the B_1 horizons. The Buckley clay is an exception and has adequate reserves, as has the A_2 horizon of the Monivae gravelly loam at the site sampled.

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Plant specimens were identified at the National Herbarium.

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APPENDIX I - Glossary of Soil Terms

Buckshot – See ferruginous concretions.

Colour – Soil colours, besides being described in common terms such as brown, red-brown, etc. may be defined in terms of the Munsell notation by matching the soil against colour charts e.g., 2.5YR 5/8 denoting, in order, hue, value and chroma, defines one particular soil colour in the red-brown range.

Concretion – A hard aggregate caused by local concentrations of compounds that irreversibly cement the soil grains together.

Consistence – Describes the behaviour of a soil when manipulated. It indicates its resistance to deformation and is a measure of the degree of cohesion of a soil, or of a soil aggregate. Terms used such as soft, hard, crumbly and plastic are self explanatory.

Ferruginous concretions – More or less rounded nodules of variable size and composition formed from the deposition of iron oxide (sometimes with other materials). They occur principally in the A_2 horizon but also may occur in the A_1 and B horizons.

Gravel – Particles larger than 2 mm diameter (as distinct from the fine earth which comprises particles smaller than 2 mm).

Horizon – A layer of soil, more or less parallel to the land surface, similar throughout and recognizably different from the material above and below. The following horizons in the soil profile may be recognized:

> ***A horizon.*** The uppermost layer where accumulation of organic matter and eluviation or removal of materials commonly occur. It may be divided into two or more subhorizons as follow:
>
> ***A_1 horizon.*** The surface soil more or less darkened by organic matter – a zone of maximum biological activity.
>
> ***A_2 horizon.*** A subsurface layer lower in organic matter than the A_1, and in consequence, usually lighter in colour.
>
> ***B horizon.*** A zone of accumulation of soil materials from the A horizon above. It may be subdivided from the top down into B_1, B_2, etc. on differences in colour, texture, structure, etc. The B_1 horizon is commonly the first zone of clay accumulation, except that an AB or transitional horizon may occur between the A and B_1 horizons.
>
> Any of the above subhorizons may be further divided on the basis of slight changes in a property, for example, the A_1 into A_{11} and A_{12}, the B_1 into B_{11} and B_{12}.
>
> ***C horizon.*** A zone less enriched from above than the B horizon and thought to be little affected by biological soil forming processes.

Ped – An individual natural soil aggregate.

Soil profile – Vertical section of soil showing the sequence of horizons from the surface to the parent material or substrata.

Soil type – The basic unit for classifying and mapping soils. It groups soils with profiles varying only within defines, narrow limits, developed from a common parent material and, following U.S. definition, has area as well as depth.

Structure – The manner and degree of natural aggregation of the primary soil particles.

Subsoil – The B_1 horizon. The ***deep subsoil*** refers to horizons below the B_1 horizon.

APPENDIX II - Analytical Methods

The methods used for the analyses shown in Table 2 and in Appendix III are given below and, except where indicated otherwise, are essentially as described by Piper (1950). All estimations were carried out on the air-dried fine earth, i.e., material passing a 2 mm round hole sieve. For calcium carbonate, phosphorus, nitrogen and organic carbon, the fine earth was further reduced to pass through a 0.5 mm sieve.

Particle Size Distribution – International "Method A". Results expressed as percentage of over dry soil.

Total Nitrogen – Kjeldahl digestion. Results given on oven dry basis.

Organic Carbon – Walkley and Black's method using a recovery factor of 1.25. Results given on oven dry basis.

Calcium Carbonate – Hutchinson and Maclennan's Method. Carbon dioxide estimated and expressed as per cent calcium carbonate in the air-dry soil.

A***vailable Potassium*** – Potassium determined in a 1:20 soil to $^{N}/_{20}$ hydrochloric acid equilibrium extract and expressed as parts per million of air dry soil.

Inorganic Phosphorus – Williams Method (1950). Phosphorus determined in a 1:40 soil to acid (2.5% acetic acid – 1% 8-hydroxyquinoline) equilibrium extract. Results expressed as parts per million of air-dry soil

Exchangeable metal Cations – Calcium, magnesium, potassium and sodium determined in N/1 ammonium acetate leachate at pH 7.0 after removal of soluble salts with 60% ethanol. The individual cations are expressed as milliequivalents per 100 g of over-dry soil and as percentages of the cation exchange capacity.

Exchangeable Hydrogen to pH 8.0 - $BaCl_2$ – triethanolamine Method as modified by Peech et al. (1962).

Cation Exchange Capacity to pH 8.0 – Sum of calcium, magnesium, potassium, sodium and hydrogen determined as above.

Chlorides – Determined by the electrometric titration method of Best and reported as sodium chloride equivalent in the oven-dry soil.

Electrical Conductivity – The conductivity of a 1:5 soil to water suspension at 20°C using the relationship % T.S.S. = E.C. in mho/cm x 330.

pH – Determined on the 1:5 soil to water suspension by the glass electrode after determination of electrical conductivity.

APPENDIX III - Field and Laboratory Data for Representative Soil Profiles

Chemical and physical data and summarised morphological descriptions are given for six profiles representing all the soil types. The location of each profile can be identified on the soil map by its profile number. Analytical methods are given in Appendix II.

The abbreviations used in the table have the following meanings:-

Hor.	Horizon. In general the designations accord with the definitions given in Appendix I.
Bdy.	Nature of the boundary with the underlying horizon: a = abrupt; c = clear; d = diffuse; g = gradual; i = irregular.
Text.	Field texture assessment: L = loam; CL = clay loam; GrL = gravelly loam; GrC = gravelly clay; MC = medium clay; HC = heavy clay; SIL = silty loam; SICL = silty clay loam.
Colour	The Munsell notation for the main colour is given. The upper affixes “f’, “d”, “m” and “s”, respectively refer to faint, diffuse, moderate and strong mottling; the lower affixes “r”, “b”, “y”, “d” and “l” signify that the subsidiary colours are, respectively, redder, browner, or yellower that the main colour, or are dark or light grey.
Gr.	Gravel expressed as percentage of the air-dry field sample.
Particle size	Refers to the fine earth: CS = coarse sand (2.0 - 0.2 mm); FS = fine sand (0.2 - 0.02 mm); Si = silt (0.02 - 0.002 mm); C = clay (0.002 mm).
LAT	Loss on acid treatment.
OC	Organic carbon.
N	Total nitrogen.
EC	Electrical conductivity.
CEC	Cation exchange capacity.
Cl	Chloride calculated as sodium chloride.

Depth	Hor & Bdy	Text. (fld)	Colour (moist)	Gr.	Particle size				LAT
					CS	FS	Si	C	
				%	%	%	%	%	%
Profile No. 1			***MONIVAE GRAVELLY LOAM***						
0 – 4	A_1c	GrL	10YR 3/2	54*	11	34	23	25	1.6
4 – 12	A_2c	GrL	10YR 3/3	45	15	33	20	28	1.1
12 – 15	B_1g	MC	10YR 4/3	6	6	19	12	59	1.5
15 – 27	B_2	HC	10YR $4/6^{s}_{r}$	19*	2	10	8	79	1.5
Profile No. 2			***MONIVAE LOAM***						
0 – 4	A_1c	CL	7.5YR 3/2	17	8	33	20	31	2.0
4 – 11	A_2g	GrL	10YR 4/2	37	27	30	18	22	1.0
11 – 13	ABg	GrC	2.5Y 4/4	23	19	19	12	49	1.0
13 – 27	B_1g	HC	10YR $5/8^{m}_{r}$	0	1	7	8	83	1.5
27 – 38	d	HC	10YR $5/5^{s}_{r}$	0	0	6	8	84	1.7
38 – 52	d	HC	10YR $5/8^{s}_{r}$	0	1	7	8	85	1.1
52 – 75		HC	10YR $4/7^{s}_{b}$	0	1	7	5	85	0.8

* Contains some rock fragments

OC	N	EC	CL	pH	Exchangeable cations						CEC	
					Ca	Mg	K	Na	H	Mg/Ca	Soil	Clay
%	%	%	%		me% / % of CEC						me%	me%
MONIVAE GRAVELLY LOAM Sample Nos. 19082 – 85/61												
6.15	.45	9	.01	5.8	8.4	2.3	.67	.24	16	0.3	28	-
					30	8	3	1	58			
1.53	.13	7	.01	6.5	5.6	2.6	.54	.26	7.8	0.5	17	-
					33	16	3	2	46			
-	-	9	.01	6.6	-	-	-	-	-	-	-	-
-	-	10	.02	6.8	-	-	-	-	-	-	-	-
Profile No. 2 MONIVAE LOAM Sample Nos. 19086 – 92/61												
4.73	.36	13	.02	6.1	8.8	3.0	.53	.36	14	0.3	27	-
					33	11	2	1	53			
1.28	.09	4	.01	6.6	5.2	1.9	.11	.22	7.5	0.3	15	-
					35	13	1	1	50			
-	-	5	.01	6.7	-	-	-	-	-	-	-	-
		9	.03	6.3	4.5	7.4	.15	.88	12	1.7	24	29
					18	30	1	4	47			
-	-	11	.04	6.3	-	-	-	-	-	-	-	-
		12	.04	6.6	3.7	9.0	.13	1.7	10	2.4	25	30
					15	36	1	7	41			
-	-	16	.04	6.7	-	-	-	-	-	-	-	-

Depth in.	Hor & Bdy	Text. (fld)	Colour (moist)	Gr. %	Particle size CS %	FS %	Si %	C %	LAT %
Profile No. 3			NORMANBY SILTY LOAM						
0 – 5	A_1ic	SiL	10YR 3/2	0	3	48	31	15	0.9
5 – 14	A_2g	L	2.5YR 5/2	0	6	51	30	13	0.3
14 – 19	ABc	CL	1.5Y $5/2^{d}_{y}$	12	16	36	21	27	1.3
19 – 38	B_1g	MC	10YR $5/4^{m}_{b}$	0	2	23	14	61	1.1
38 – 48*	?	MC	9YR $6/8^{s}_{rl}$	17	10	22	14	54	1.4
57 – 75	g	MC	10YR $3/6^{s}_{l}$	0	5	23	14	56	1.3
* Horizon continues to 57 in. but sampled only 38-48 in.									
Profile No. 4			***YATCHAW CLAY LOAM***						
0 – 8	A_1c	SiCL	10YR 2/1	0	1	40	31	23	1.1
8 – 13	A_2c	SiL	10YR 4/1	0	3	44	34	18	0.6
13 – 16	ABc	CL	10YR 4-5/1	15	16	36	26	22	0.8
16 – 26	B_1?	HC	2.5Y $3/2^{f}_{y}$	0	1	19	14	64	2.3
29 – 38	B_2?	HC	2Y 6/8 $5/4^{m}$	0	1	19	15	65	2.0
38 – 52	? ?	HC	10YR $5/8^{m}_{g}$	0	1	27	26	46	1.6
52 – 66	?	HC		0	1	27	27	43	5.1*

* including 3.2% $CaCO_3$

OC	N	EC	CL	pH	Exchangeable cations						CEC	
					Ca	Mg	K	Na	H	Mg Ca	Soil	Clay
%	%		%		me% / % of CEC						me%	me%
NORMANBY SILTY LOAM Sample Nos. 19093 – 98/61												
2.32	.16	6	.01	5.9	3.0	1.6	.24	.35	9.0	0.5	14	-
					21	11	2	3	64			
0.47	.03	4	.00	6.3	1.7	1.2	.07	.17	3.4	0.7	6	-
-	-	5	.01	6.5	-	-	-	-	-	-	-	-
-	-	9	.01	6.5	4.6	7.4	.28	1.0	9.0	1.6	22	37
					21	33	1	5	40			
-	-	8	.02	6.7	3.9	7.1	.22	1.2	8.3	1.8	21	38
					19	34	1	7	40			
-	-	11	.02	6.9	-	-	-	-	-	-	-	-
Profile No. 4 YATCHAW CLAY LOAM Sample Nos. 19099 – 105/61.												
3.71	.25	6	.01	5.7	5.6	2.5	.18	.36	13	0.4	21	-
					26	12	1	2	60			
1.06	.09	5	.01	6.1	3.4	2.1	.08	.25	5.2	0.6	11	-
					31	19	1	2	47			
-	-	5	.01	6.6	-	-	-	-	-	-	-	-
-	-	7	.02	6.7	7.8	9.4	.35	1.4	10	1.2	29	46
					27	32	1	5	35			
-	-	11	.02	7.0	-	-	-	-	-	-	-	-
-	-	13	.02	7.8	8.5	11.2	.25	1.9	3.7	1.3	26	56
					33	44	1	8	15			
-	-	30	.02	8.7	-	-	-	-	-	-	-	-

Depth in.	Hor & Bdy	Text. (fld)	Colour (moist)	Gr. %	Particle size CS %	 FS %	 Si %	 C %	LAT %
Profile No. 5			***TYPE A***						
0 – 4	Aia	CL	10YR 2/1	0	1	42	33	23	1.6
4 – 16	$B_{11}g$	MC	10YR 3/1	0	1	27	20	51	1.9
16 – 29	$B_{12}g$	MC	10YR 3/1	0	1	22	19	58	2.2
29 – 48	B_2?	MC	2.5Y 5/2	0	0	23	20	51	4.0*
48 – 68	?	LC		0	1	29	28	44	1.5+
* including 1.7% $CaCO_3$ + including less than 0.03 % $CaCO_3$									
Profile No. 6			***BUCKLEY CLAY***						
0 – 5	A g	HC	10YR 2/1	0	1	14	23	56	3.2
5 – 13	$B_{11}g$	HC	10YR 3/0	0	1	12	20	63	2.9
13 – 27	$B_{12}g$	HC	10YR 3/0	0	1	11	14	70	2.7
27 – 42	g	HC	10YR $3/0^{d}_{y}$	0	0	10	12	75	3.1
42 – 60	d	HC	5Y $6/3^{f}_{b}$	0	0	9	12	77	2.9*
60 – 80		C	2.5Y $6/1^{m}_{b}$	0	0	14	16	68	2.4

* including less than 0.03% $CaCO_3$

OC %	N %	EC	Cl	pH	Exchangeable cations						CEC	
					Ca me% / % of CEC	Mg	K	Na	H	Mg/Ca	Soil %	Clay me%
TYPE A					***Sample Nos. 19106-10/61***							
4.97	.37	9	.02	5.6	5.2	3.4	.39	.54	15.1	0.7	25	-
					21	14	2	2	61			
1.44	.13	9	.02	6.5	9.3	13.4	.33	2.4	10.8	1.4	36	71
					26	37	1	7	30			
-	-	27	.05	7.6	-	-	-	-	-	-	-	-
-	-	67	.13	8.6	-	-	-	-	-	-	-	-
-	-	52	.12	8.2	-	-	-	-	-	-	-	-
BUCKLEY CLAY					***Sample Nos. 19111-16/61***							
5.30	.38	10	.01	5.8	11.5	14.6	.88	1.1	19.8	1.3	48	-
					24	30	2	2	41			
2.81	.20	9	.02	6.4	13.1	19.8	.61	2.4	16.9	1.5	53	84
					25	38	1	5	32			
-	-	18	.04	6.8	14.9	23.4	.62	3.5	12.6	1.6	55	79
-	-	45	.11	7.6	-	-	-	-	-	-	-	-
-	-	66	.14	7.9	13.5	26.0	.77	5.0	4.5	1.7	50	65
					27	52	2	10	9			
-	-	57	.14	7.8	-	-	-	-	-	-	-	-