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HISTORIC MEASUREMENTS OF RADIOCARBON IN NEW ZEALAND SOILS

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ABSTRACT. Extensive measurements of radiocarbon have been used in New Zealand since the mid-1960s to follow carbon (C) movement and turnover in soils. We present here unpublished radiocarbon (^{14}C) measurements on a range of eight New Zealand soils with details of the sites, ecosystems, climates, soil descriptions and associated analytical data. An overview is also given of published ^{14}C measurements on soils, and the use of these measurements to model soil C turnover.

INTRODUCTION

New Zealand stretches *ca.* 2000 km along a north-south axis, spanning from 34° to 47°S in the southwest Pacific. The country is more remote from its nearest neighbor than any other global landmass. This isolation coupled with a high degree of climatic, geological, soil and biological diversity compressed into just 270,000 km^2, and the relative freedom from industrial pollution, provide unique opportunities for investigating surface-atmosphere exchange processes of global significance.

Furthermore, relatively undisturbed remnants of indigenous ecosystems of great antiquity are available for direct comparison with the introduced pastures and planted forests that replaced them over large areas, particularly of lowland New Zealand. It is against this background that in the early 1960s New Zealand nuclear and soil scientists recognized the opportunities for investigating these surface-atmosphere exchange processes (Rafter *et al.* 1965), provided by the then rapidly rising atmospheric concentration of radiocarbon from nuclear weapons tests that had commenced in 1954. In 1962, the New Zealand Radiocarbon Laboratory (NZRL), which was part of DSIR's Institute of Nuclear Sciences until July 1992, began analyzing anthropogenic ^{14}C in New Zealand soils. The first systematic mapping and classification of New Zealand soils was being concluded at this time (New Zealand Soil Bureau 1968), so that a representative range of well characterized sites and soils was immediately available for investigating soil dynamic processes, including rates of organic matter turnover. This research, using well-defined soil sequences to investigate the main soil forming factors (*e.g.,* Stevens and Walker 1970; Jackman 1964), soon revealed the dynamic character of soil organic matter (SOM), and illustrated the unique opportunities New Zealand offered for understanding and quantifying the processes of ecosystem development. Thus, the scene was set for using the ^{14}C enrichment of the biosphere through photosynthesis to trace the pathways, and measure the fluxes, of C in soil. Subsequently, through a program of extensive measurements of δ^{13}C and Δ^{14}C in New Zealand soils and plants that followed, it eventually became possible to model biogeochemical pathways for the movement and turnover of C in soil (Rafter and Stout 1970; O'Brien and Stout 1978; O'Brien *et al.* 1981; O'Brien 1984, 1986).

Our aims in this report are 1) to list unpublished Δ^{14}C and δ^{13}C measurements made on New Zealand soil samples from eight profiles that have been well described and analyzed for their chemical and physical properties, and 2) to review briefly research previously published that used anthropogenic ^{14}C to investigate the dynamics of soil organic C.

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METHODS

Sites and Soils

The eight sites (Fig. 1) and soils listed under "Summary of Unpublished ^{14}C Measurements on New Zealand Soils" reflect the wide diversity of climates and soil types represented in New Zealand. Descriptions are given for each of the eight sites and soils listed. Analytical data for $\Delta^{14}C$, $\delta^{13}C$ and a range of soil chemical and physical properties are presented by horizon; designations for soil horizons follow the convention of Clayden and Hewitt (1989).

Analytical Methods and Definitions

The C isotope results reported here were all obtained by stable-isotope mass spectrometry and by gas-counting techniques made on pretreated soils. The pretreatment comprises a hot-water wash, acid treatment (usually 2% phosphoric acid to remove carbonates), and water rinse. Values for $^{13}C/^{12}C$ ratios and for $^{14}C/(^{12}C + ^{13}C)$ are expressed relative to standards after Craig (1953) and Stuiver and Polach (1977), respectively, by Equations (1)–(3).

$$\delta^{13}C(‰) = 1000\,[(R_{13}/R_o) - 1] \tag{1}$$

$$\left(1 + \frac{\Delta^{14}C}{1000}\right) = \left(1 + \frac{\delta^{14}C}{1000}\right)\left(\frac{975}{(1000 + \delta^{13}C)}\right)^2 \tag{2}$$

$$\delta^{14}C(‰) = 1000\,[(R_{14}/R_{std}) - 1]\ . \tag{3}$$

In these equations, R_{13} and R_o are the $^{13}C/^{12}C$ ratios in the soil C samples and isotope standard (Pee-Dee Belemnite, or PDB), respectively; R_{14}/R_{std} is the ^{14}C content of the sample per gram of C, decay-corrected to the time of sampling, relative to that for the NIST radiometric standard (0.95 oxalic acid, HOxI), decay-corrected back to 1950. By convention, $\delta^{13}C$, $\delta^{14}C$ and $\Delta^{14}C$ are expressed in ‰. Since in most New Zealand ecosystems soil $\delta^{13}C$ values are consistently close to –25‰, there is no significant numerical distinction between $\Delta^{14}C$ and $\delta^{14}C$.

Soil Chemical and Physical Analyses

The methods for preparing soil samples for analysis, and the analytical methods themselves, are fully described by Blakemore *et al.* (1987). Carbon contents (wt%) were determined by wet oxidation (Metson *et al.* 1979) prior to 1967, and subsequently by dry combustion (Blakemore *et al.* 1987). Although microbial biomass was not measured on the soil samples listed, measurements have been reported for some corresponding topsoils as follows: Carrick, Tima (Ross *et al.* 1980); Judgeford (Ross *et al.* 1990); Egmont (Ross 1992). The isotope, and soil chemical and physical data were largely retrieved from the NZRL archives, and the National Soils' Database, respectively.

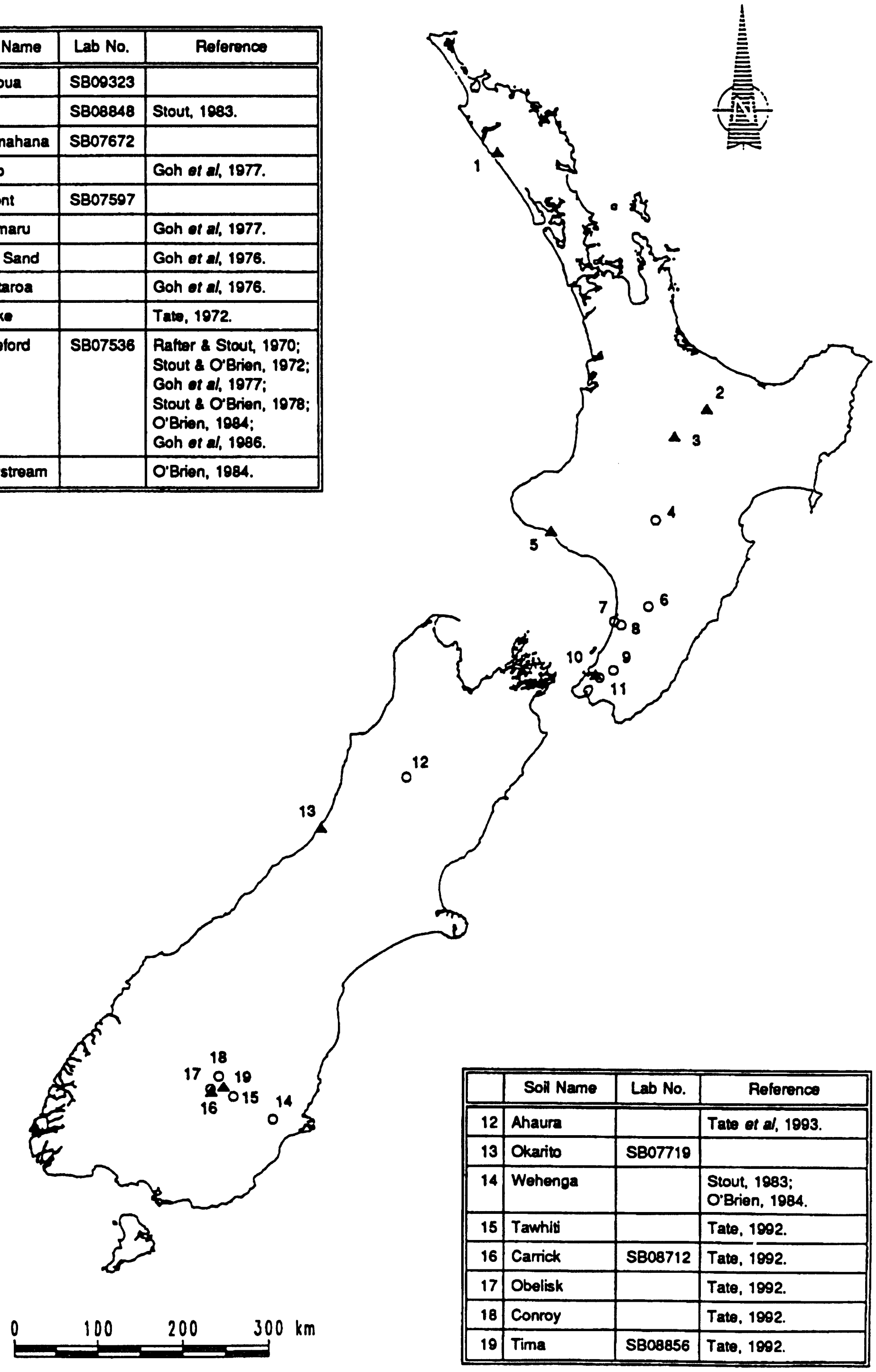
RESULTS

Summary of Unpublished ^{14}C Measurements on New Zealand Soils

The locations of the sites for the eight soils listed are shown in Figure 1, together with sites for which $\Delta^{14}C$ and $\delta^{13}C$ measurements have already been published.

For each of the eight soils, we present two tabulations. The first contains site information, including location, climate, site, geology, land use, vegetation and soil classification, as well as a brief description of the soil by horizon. The second tabulation presents the isotope, soil chemical and physical analyses, along with explanatory notes as appropriate. All soil samples are identified by two laboratory codes, one for the isotope analyses designated "NZ", and the other, "SB", for the soil data. In

	Soil Name	Lab No.	Reference
1	Waipoua	SB09323	
2	Tihoi	SB08848	Stout, 1983.
3	Rotomahana	SB07672	
4	Taupo		Goh *et al*, 1977.
5	Egmont	SB07597	
6	Tokomaru		Goh *et al*, 1977.
7	Dune Sand		Goh *et al*, 1976.
8	Koputaroa		Goh *et al*, 1976.
9	Kaitoke		Tate, 1972.
10	Judgeford	SB07536	Rafter & Stout, 1970; Stout & O'Brien, 1972; Goh *et al*, 1977; Stout & O'Brien, 1978; O'Brien, 1984; Goh *et al*, 1986.
11	Silverstream		O'Brien, 1984.



	Soil Name	Lab No.	Reference
12	Ahaura		Tate *et al*, 1993.
13	Okarito	SB07719	
14	Wehenga		Stout, 1983; O'Brien, 1984.
15	Tawhiti		Tate, 1992.
16	Carrick	SB08712	Tate, 1992.
17	Obelisk		Tate, 1992.
18	Conroy		Tate, 1992.
19	Tima	SB08856	Tate, 1992.

Fig. 1. Map of New Zealand (latitudes from 34 to 47°S) showing the location of North and South Island sites and soils (▲) described in this report. Sites where isotope data for soils has previously been published (o) are also shown.

most cases, the $\Delta^{14}C$ and $\delta^{13}C$ measurements were made on the same soil samples as for the chemical and physical analyses. The exception was the Tihoi soil (Fig. 1, site 2), where the C isotope analyses reported are for soil samples from a nearby site also under pasture. The horizons analyzed in the Rotomahana soil for $\Delta^{14}C$ and $\delta^{13}C$ straddle the boundary between the base of the contemporary soil, formed on volcanic mud erupted in 1886, and the soil beneath. Although many measurements of $\Delta^{14}C$ and $\delta^{13}C$ have been made, and reported, on Judgeford soils (see site summary in Fig. 1), the data presented here for a full profile has not been reported previously. Precisions for the $\delta^{13}C$ isotope data are typically ±0.1‰ (standard deviation).

OVERVIEW OF PUBLISHED ^{14}C MEASUREMENTS ON NEW ZEALAND SOILS

Several factors including climate, ecosystem and soil type, resource quality and soil biology, together regulate the turnover of SOM. The effects of some of these factors on organic matter turnover have been investigated in New Zealand soils using natural ^{14}C enrichment.

Climate

Stout and O'Brien (1972) contrasted the ^{14}C enrichment of the litter and soils in a warm temperate New Zealand kauri (*Agathis Australis*) forest (latitude 36°S) with two topsoils in a tropical mixed kauri-broadleaved forest in New Hebrides (19°S). They concluded from the high level of ^{14}C found in the two tropical topsoils, coupled with their relatively thin litter layers compared to the temperate forest, that C was cycling much more rapidly in the former. However, a highly productive temperate New Zealand topsoil was enriched with ^{14}C to a similar extent as the two tropical topsoils.

More recently, the ^{14}C measured in five profiles of a soil climosequence in native tussock grassland in South Island, New Zealand, first published by Stout and Rafter (1978), was used in conjunction with total soil C contents to investigate the possible effects of global warming on soil C turnover (Tate 1992). The climates across the sequence ranged from cold to warm temperate. A soil C turnover model (O'Brien 1984) indicated that turnover rates for three of the soils were in the range expected for New Zealand grassland soils. For two of the soils, however, much lower levels of ^{14}C indicated unexpectedly slow turnover rates that were attributed to a memory effect from the former beech forest that grew on these sites in prehistoric times. Local site factors including intermittent waterlogging may also have impeded decomposition processes and affected the overall soil C balance (Tate *et al.* 1995).

Ecosystem Type

The types of vegetation and soil can have a strong influence on the pattern of ^{14}C distribution in soils (Rafter and Stout 1970). Whereas $\Delta^{14}C$ in pasture grasses reflected the composition of atmospheric CO_2, during the period of rapid change in the 1960s, $\Delta^{14}C$ in beech leaves lagged behind that of the atmosphere. Rafter and Stout (1970) attributed this lower $\Delta^{14}C$ to mixing of photosynthesized C during a two-year period of beech leaf growth. $\Delta^{14}C$ in the beech litter was measured annually for seven years from 1953, and again from 1964 until 1967. Comparison of the soil profiles beneath these two vegetation types indicated a different distribution pattern of $\Delta^{14}C$. The upper soil horizon under the pasture was only slowly enriched with "bomb" ^{14}C, and the subsoil had very low $\Delta^{14}C$ values. By contrast, the litter horizon of the southern beech (near site 11, Fig. 1), and the deeper soil horizons, showed that appreciable ^{14}C enrichment had occurred. Thus, C entering the beech profile was more mobile than that entering the pasture profile. In the latter, plant residues were decomposed upon entering the soil, and released more rapidly back to the atmosphere as CO_2. Rafter and Stout

(1970) presented ^{13}C and ^{14}C data for five different soil types, although not all horizons were analyzed, and little accompanying site and soil data were recorded.

In a comparison of two adjacent ecosystems on similar soil types near Wellington—an old-growth, lowland southern beech forest and a productive pasture—Tate (1972) found that ^{14}C was again restricted to the topsoil under the pasture, but occurred throughout the soil profile (to 0.38 m depth) under the beech forest. The ^{14}C in the soils and their chemically separated fractions (humic and fulvic acids) were used to confirm that soil polyphenols in the subsoil beneath the pasture were derived predominantly from the original beech forest. The ^{14}C in the soil beneath this and a nearby beech forest are discussed in more detail elsewhere (Stout and O'Brien 1972; Stout, *et al.* 1976; O'Brien 1984).

More recently, Tate *et al.* (1993) used $\Delta^{14}C$ in soil profiles beneath an old-growth southern beech forest together with soil chemical, physical and biological data to calculate C turnover rates. The accumulation of old C in these soils was attributed to the effects on soil C turnover of a long history of soil mixing by tree overturn in this ancient forest. This process is not observed in grassland soils.

Soil Type

The age of SOM appears to be more closely related to soil type, and soil forming processes, than to climate (Stout *et al.* 1981). This was shown in investigations of a chronosequence of New Zealand soils developed on wind-blown sand. Soil ages along the chronosequence ranged from 20 to *ca.* 10,000 yr (Goh and Stout 1972; Goh *et al.* 1976). The mass of total organic C in the soil profiles and the carbon isotope composition of specific soil horizons were presented in these investigations. The rate of accumulation of soil organic C was rapid in the first 500 yr of soil formation, with a considerable range in the age of the SOM as a function of depth within a profile. The younger soils were more enriched with ^{14}C, with topsoils more enriched than subsoils (Goh and Stout 1972). Goh *et al.* (1976) attempted to interpret ^{14}C levels in the classical humus fractions of some of these soils (humic and fulvic acids, and humins) in terms of possible genetic relationships between them, but the outcome was mainly equivocal.

In a closely related study, Goh *et al.* (1977) found that the ^{14}C levels in the humus fractions varied both within and among soil types, as well as between topsoils and subsoils. They studied a range of soil types from several sites in grasslands of mainly low to medium fertility. These soil types included a Fluvaquent, Typic Fragiaqualf, Typic Dystrochrept and Umbric Vitrandept (Soil Survey Staff 1992). It appeared that ^{14}C levels were primarily determined by the stage of decomposition of the organic matter, rather than by soil type. These studies on soil humus fractions have added to the weight of evidence (O'Brien *et al.* 1981) indicating that these classical fractions have limited value in unraveling the complex biological pathways involved in SOM turnover. The effect of soil type on organic matter turnover in New Zealand is expressed most strongly in those soils in North Island containing short-range order minerals, *e.g.*, allophane (Jackman 1964). Current research (K. R. Tate, unpublished results) seeks to quantify the influence of allophane and ferrihydrite on organic matter turnover, and for this purpose, the distribution of "bomb" ^{14}C in three volcanic ash soils is being investigated.

Soil Biological Activity

Earthworms, both native and introduced, have an important influence on New Zealand soils by comminuting and incorporating plant residues, thereby accelerating organic matter turnover rates. Stout (1983) and O'Brien (1984) used soil ^{14}C measurements on different soil types in attempts to quantify the effect of earthworms at sites with known populations. In the absence of earthworms there was little evidence for downward movement of ^{14}C in the soil and decomposition rates were slow. Stout (1983) reported total masses of soil organic C, ^{14}C and ^{13}C for several Tihoi (Site 2, Fig. 1) and Wehenga soil profiles without worms and with known worm populations. These studies showed that the presence of earthworms had increased topsoil organic matter contents, and accelerated decomposition including that of old C. O'Brien (1984) modeled the turnover of soil C using the profile distributions of "bomb" ^{14}C in the soil profiles, and found that in the South Island Wehenga soil the presence of earthworms had caused organic matter turnover rates to increase fivefold.

Modeling SOM Turnover

Much of the research in New Zealand on the use of "bomb" ^{14}C to investigate soil C turnover has involved investigating Judgeford soils near Wellington. O'Brien and Stout (1978) developed a steady-state model to represent organic C turnover, and used "bomb" ^{14}C and soil organic C measurements in Judgeford soil profiles sampled over a *ca.* 15-yr period to evaluate the model parameters: C input, decomposition time and downward diffusivity in the soil profile. Estimates of these model parameters have subsequently been made for five New Zealand pasture soils and a forest soil (O'Brien 1984), five soils in native tussock grassland (Tate 1992), and an old-growth southern beech forest (Tate *et al.* 1993). Evidence from detailed ^{14}C and ^{13}C measurements made on a soil core to the base of the Judgeford soil (Goh *et al.* 1984), and in a nearby soil (O'Brien 1986), supported the hypothesis in the model that the concentration of old (inert) C— possibly polymethylene C (Theng *et al.* 1992)—remains constant with depth in the profile.

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Site 1: Location and Soil Description

Soil name: Waipoua Clay					Lab no. SB09323
	Site, Soil Descriptions and Analytical Data				Date sampled: 19 Feb. 1972
Latitude:	35°39′S	Longitude:	173°34′		
N.Z. genetic classification:	Brown granular clay	NZSC:	Acidic orthic granular soil	FAO:	Humic acrisol
Survey:	North Auckland	Region:	Northland, North Island		
Location:	Parliament grove, Waipoua forest, 1.2 km NW of the bridge at intersection of main road and forest HQ road				
Topdressing:	Nil				
Annual rain:	1648 mm	Elevation:	170 m	Mean annual temp:	14°C
Landform:	Ridge				
Microrelief:	Flat	Slope:	10°	Aspect:	225°
Slope movement:	Not known	Topsoil loss:	0%		
Drainage:	Moderately good	Land use:	Unused-natural		
Improvements:	Nil				
Vegetation:	Kauri forest, *Agathis australia, Podocarpus ferugineus*				
Parent materials:	Strongly weathered basalt, weathered andesitic				
Notes:	Pit to 31 cm. Auger 1 (50–61 cm), Auger 2 (61–92 cm), Auger 3 (61–92 cm). Augers 30 cm triangle apart. At −2.0 cm transition litter/mineral soil with many roots up to 2 cm. Also sampled at 61–92 cm yellowish-red, red, and dark brown (5YR 4/6, 2.5YR 4/6 and 7.5YR 4/4) silty clay; very firm; mod. coarse and med. nut breaking to fine and very fine blocky and nut structure; fine structure in above horizons may be inherited from the weathered rock.				

Horizon	Depth (cm)	Horizon description
L	−22–19	Decomp. litter coated with reddish humus; Kauri leaves, bark, laminae of cones, twigs, male flowers; indistinct boundary.
F	−19–15	Reddish-black (10R 2/1) peaty; to 2.5YR 2/2; within wiry mattress of f. roots; abund part decomp. litter as above; few gum frag.; ab. loose root nodules.
H1	−15–10	Reddish-black (10R 2/1) peaty; very weak soil strength; weakly developed very fine crumb structure, v. abund. fibers; decaying monocot roots; root nodules; indistinct boundary.
H2	−8–0	Dark reddish-brown (5YR 2/2) clay; strongly developed medium granular plus strongly developed fine granular structure; and very fine cast granules; 20% med nut; some gum fragments; distinct boundary.
AB	0–15	Dark brown (7.5YR 3/2) clay; moderately firm soil strength; moderately developed coarse nut breaking to medium nut structure; to 7.5YR 4/2 and 2/2; also f. nut and v.f. block struct.; rootless thru' peds; indistinct boundary.
Bt1	15–31	Dark brown (7.5YR 3/2) clay; moderately firm soil strength; moderately developed coarse nut breaking to fine blocky structure; indistinct boundary.
Bt2	31–50	Brown to dark brown (7.5YR 4/2) clay; moderately firm soil strength; strongly developed medium blocky plus strongly developed very fine granular structure; to 7.5YR 4/4; friable when disturbed; also v. fine block; indistinct boundary.
BC1	50–61	Brown to dark brown (7.5YR 4/4) clay; moderately firm soil strength; moderately developed medium nut breaking to fine blocky structure; also 7.5YR 5/8–8/6 gritty clay loam weathering P.M.; friable when disturbed; also v. fine block; indistinct boundary.
BC2	61–91	Reddish-brown (5YR 4/4) silty clay loam; very firm soil strength; moderately developed very coarse nut breaking to fine blocky structure; to 7.5YR 5/6; also fine and very fine block structure.

Site 1: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties								
				Δ14C ‰	δ13C ‰	C %	N %	C/N	CEC† me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
9323A		L	-22–19			50.0	0.83	60	79.2		4.1	39		
9323B	1439	F	-19–15	18.3 ± 7.0	-25.2	49.0	1.21	40	130.5		4.1	40		
9323C	1440	H1	-15–10	-4.9 ± 6.9	-25.2	50.0	1.29	39	125.5		3.5	40		
9323D	1443	H2	-8–0	-17.0 ± 7.0	-24.0	19.0	0.66	29	57.7		3.8			
9323E	1557	AB	0–15	-31.8 ± 6.9	-25.7	7.8	0.32	24	34.9		4.3			
9323F	1573	Bt1	15–31	-35.1 ± 6.8	-26.5	4.5	0.22	20	26.2		4.8			
9323G	1574	Bt2	31–50	-72.2 ± 6.7	-25.8	3.1	0.14	22	20.8		4.7			
9323H		BC1	50–61			1.7	0.07	24	16.2		4.7			
9323I		BC2	61–92			0.9	0.03	*	15.1		4.9			
9323J		BC2	61–92			1.2	0.04	*	14.1		4.7			

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties						
				Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 mm	% Silt 0.02–0.002 mm	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
9323A		L		0.04					Predominantly kaolin Small amounts of vermiculite, quartz	L, F, H litter horizon bulk densities (italics) are approximate, est. from means for litters under southern beech and mixed podocarp/broadleaf forest. Bulk densities (italics) for AB, Bt horizons estimated from 5 brown granular clay soils at similar depths. AB mean = 0.94 std. dev. = 0.17 Bt mean = 0.93 std. dev. = 0.15 Blank spaces in tables indicate no available data. *C/N ratio not calculated when N < 0.05. †CEC = cation exchange capacity; me % = c mol(+) kg⁻¹
9323B	1439	F		0.08						
9323C	1440	H1		0.08						
9323D	1443	H2		0.08						
9323E	1557	AB		*0.94*						
9323F	1573	Bt1		*0.93*						
9323G	1574	Bt2		*0.93*						
9323H		BC1								
9323I		BC2								
9323J		BC2								

Site 2: Location and Soil Description

Soil name: Tihoi Loamy Sand — Lab no. SB08848

Site, Soil Descriptions and Analytical Data — Date sampled: 27 Mar. 1973

Latitude: 38°35′S — Longitude: 175°57′

N.Z. genetic classification: Podzolized yellow-brown pumice soil — NZSC: Humose orthic podzol — FAO: Orthic podzol

Survey: Soils of Taupo region — Region: Taupo, North Island

Location: Lomond Road, 1 km east of obsidian cutting, cutting of old scoria quarry.

Topdressing: Not known

Annual rain: 2000 mm — Elevation: 610 m — Mean annual temp: 12°C

Landform: In rolling country

Microrelief: Flat — Slope: 4° — Aspect: 360°

Slope movement: Not known — Topsoil loss: 0%

Drainage: Well — Land Use: Rough grazing

Improvements: Oversown, ploughed

Vegetation: Browntop, Yorkshire fog, Thistles, White clover

Parent materials: Taupo pumice overlying weathered rhyolitic tephra

Notes: Erosion – nil

Site 2: Location and Soil Description *(Continued)*

Horizon	Depth (cm)	Horizon description
Ap	0–9	Black (10YR 2/1) loamy sand; very weak soil strength; weakly developed fine granular plus weakly developed fine crumb structure; abundant live roots; tending to 10YR 3/2; few fine lapilli; distinct irregular boundary.
Ea	11–9	Greyish brown (10YR 5/2) fine sand; moderately weak soil strength; weakly developed fine crumb plus weakly developed fine granular structure; many medium and fine lapilli; distinct smooth boundary.
Bh	21–37	Dark reddish brown (5YR 3/4) loamy sand; moderately weak soil strength; weakly developed fine nut plus weakly developed fine granular structure; few medium and fine lapilli; distinct smooth boundary.
Bs	40–50	Strong brown (7.5YR 5/6) gritty sand; moderately firm soil strength; massive; distinct smooth boundary
2Cu1	52–78	Yellowish brown (10YR 5/8) to 7.5YR 5/8 (and much darker grey rhyolite) pumice gravel; loose soil strength; single grain; Taupo lapilli; distinct irregular boundary.
3Cu2	80–105	Light yellowish brown (2.5Y 6/4) gritty sand; loose soil strength; massive breaking to single grain; pumice gravel; firm in situ; sharp smooth boundary.
3Cu3	105–107	Grey (5Y 5/1) loamy sand; moderately firm soil strength; massive; (Rotongaio Ash); sharp smooth boundary.
3Cu4	109–119	Yellowish brown (10YR 5/4) gritty sandy loam; moderately weak soil strength; weakly developed granular structure; greasy.

Site 2: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties								
				$\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	C %	N %	C/N	CEC† me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
8848A	5986	Ap	0–9	142.8 ± 4.4	-26.6	4.6	0.30	15	13.5		6.0	57	29	28
8848B	5987	Ea	11–19	58.6 ± 5.8	-25.9	4.1	0.31	13	12.3		6.1	63	22	41
8848C	5988	Bh	21–37	0.4 ± 7.2	-25.9	2.8	0.16	18	13.1		6.2	43	21	22
8848D		Bs	40–50			2.0	0.11	18	8.6		6.1	39	12	27
8848E		2Cu1	52–78			0.8	0.04	*	4.9		6.4	40	2	38
8848F		3Cu2	80–105			0.7	0.03	*	3.7		6.5	37	1	36
8848G		3Cu3	105–107			0.8	0.08	10	7.2		6.6	23	6	17
8848H		3Cu4	109–119			1.2	0.05	24	7.2		6.4	34	20	14

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties						
				Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 mm	% Silt 0.02–0.002 mm	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
8848A	5989	Ap	0–9	0.89		80	18	2	Predominantly: Volcanic glass (Allophane at depth) Small am'ts of: smectite and kaolin	$\Delta^{14}C$ and $\delta^{13}C$ analyses of soil horizons are from a Tihoi Soil at a nearby site under pasture, altitude 600 m. Horizons, depths corresponding to these C isotope analyses: Ap 0–8 cm, Bsh 8–27 cm, Bs 27–44 cm. Blank spaces in tables indicate no available data. *C/N ratio not calculated where N <0.05. †CEC = cation exchange capacity; me % = c mol(+) kg^{-1}
8848B	5987	Ea	11–19	0.72		75	22	3		
8848C	5988	Bh	21–37	0.90		89	7	4		
8848D		Bs	40–50	1.17		89	7	4		
8848E		2Cu1	52–78	0.91		93	6	1		
8848F		3Cu2	80–105			92	7	1		
8848G		3Cu3	105–107			71	19	10		
8848H		3Cu4	109–119			73	16	11		

Site 3: Location and Soil Description

Soil name: Rotomahana Sandy Loam					Lab no. SB07672
		Site, Soil Descriptions and Analytical Data			Date sampled: 22 Sept. 1960
Latitude:	38°17′S	Longitude:	176°23′		
N.Z. genetic classification:	Recent soil	NZSC:	Typic tephric recent soil	FAO:	Vitric andosol
Survey:	1962 conference site	Region:	Rotorua, North Island		
Location:	Waimangu Rd, 0.4 km west along road from tearooms, east side of road reserve				
Topdressing:	Not known				
Annual Rain:	1270 mm	Elevation:	460 m	Mean annual temp:	13°C
Landform:	Ridge				
Microrelief:	Flat	Slope:	5°	Aspect:	270°
Slope movement:	Not known	Topsoil loss:	Not known		
Drainage:	Well	Land use:	Unused natural		
Improvements:	Nil				
Vegetation:	Bracken fern, mahoe, coprosma, kamahi, lupin				
Parent Materials:	Rotomahana mud, hydrothermally altered rhyolitic ejecta from Lake Rotomahana's 1886 eruption				
Notes:					

Horizon	Depth (cm)	Horizon description
L	–2–1	Litter; mainly bracken remains.
H	–1–0	Brown organic matter.
Ah1	0–3	Black (10YR 2/1) sandy loam; moderately firm soil strength; moderately developed fine granular structure; many live roots; sharp boundary.
Ah2	3–8	Weak red (2.5YR 5/2) silt loam; moderately weak soil strength; moderately developed fine granular plus medium nut structure; many live roots; diffuse boundary.
Cu	8–74	Light grey (5Y 7/2) bands; pale olive grey (5Y 6/2) bands; silt loam.
2bAh	74–82	Black (10YR 2/1) fine sandy loam; moderately firm soil strength; weakly developed fine granular structure;
2bAB	82–92	Very dark brown (10YR 2/2) fine sandy loam; moderately weak soil strength; moderately developed fine granular plus medium nut structure
3bCu	92–98+	Loose soil strength; single grain; pumice travel
2bAB	82–92	Very dark brown (10YR 2/2) fine sandy loam; moderately weak soil strength; moderately developed fine granular plus medium nut structure.
3bCu	92–98+	Loose soil strength; single grain; pumice gravel.

Site 3: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties								
				$\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	C %	N %	C/N	CEC† me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
		L												
		H												
7672A		Ah1	0–3			9.9	0.54	18	32.8	5.7	5.8	67	36	31
7672B		Ah2	3–8			1.3	0.07	19	11.3	5.5	5.8			
7672C	5729	Cu	30–61	–436.9 ± 13.9	–26.8	0.2	0.02	*	14.0	6.2	6.4	29	0	29
7672D	5727	2bAh	74–79	–33.8 ± 3.8	–25.8	3.6	0.21	17	18.3	6.1	5.4			
7672E	5728	2bAB	84–91	–94.9 ± 5.3	–24.8	3.4	0.14	24	12.9	6.2	5.5			
7672F		Ah	0–8			1.9	0.12	16	11.1	5.7	5.9			

Site 3: Measurements *(Continued)*

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties: Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 mm	% Silt 0.02–0.002 mm	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
		L							Predominantly: smectite. Small amounts of: mica, allophane, kaolin	7672F was a bulk sample from 2–10 cm of the topsoil. Dry bulk density figures for 7672A,B were assumed from the measured value for 7672F. Blank spaces in tables indicate no available data. *C/N ratio not calculated where N <0.05. †CEC = cation exchange capacity; me % = c mol(+) kg⁻
		H								
7672A		Ah1	0–3	0.69		61	25	12		
7672B		Ah2	3–8	0.69						
7672C	5729	Cu	30–61	1.20		50	36	13		
7672D	5727	2bAh	74–79	0.69						
7672E	5728	2bAB	84–91							
7672F		Ah	0–8	0.69						

Site 5: Location and Soil Description

Soil name: Egmont Black Loam — Lab no: SB07597

Site, Soil Descriptions and Analytical Data — Date sampled: 1 Mar. 1960

Latitude:	39°37′S	Longitude:	174°18′		
N.Z. genetic classification:	Yellow brown loam	NZSC:	Typic Orthic allophanic soil	FAO:	Ochric andosol
Survey:	N.Z. soils	Region:	Hawera, North Island		
Location:	Rear of Whareroa Social Hall, Whareroa Rd.				
Topdressing:	Fertilized				
Annual rain:	1020 mm	Elevation:	91 m	Mean annual temp:	14°C
Landform:	Rolling country				
Microrelief:	Flat	Slope:		Aspect:	
Slope movement:	Nil	Topsoil loss:	Not known		
Drainage:	Well	Land use:	Long-term grass		
Improvements:	Ploughed				
Vegetation:	Cocksfoot, sweet vernal, ryegrass				
Parent materials:	Fine andesitic ash				
Notes:	Mount Taranaki (Egmont) last erupted in AD 1755				

Horizon	Depth (cm)	Horizon description
Ap	0–20	Black (10YR 2/1) loam; moderately weak soil strength; moderately developed fine nut structure; no mottles; abundant live roots; distinct irregular boundary.
Bw1	20–46	Brown (10YR 5/3) loam; very weak soil strength; weakly developed medium nut breaking to crumb structure; no mottles; common live roots; some small pieces of weathered pumice; distinct wavy boundary.
Bw2	46–66	Yellowish brown (10YR 5/4) silt loam; moderately firm soil strength; massive plus weakly developed fine blocky structure; no mottles; common live roots; some small pieces of weathered pumice; indistinct boundary.
BC	66–70+	Dark yellowish brown (10YR 4/4) silt loam; very firm soil strength; massive; no mottles; few live roots; some small pieces of weathered pumice.

Site 5: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes: $\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	Chemical Properties: C %	N %	C/N	CEC† me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
7597A		Ap	0–8			12.3	0.93	13	36.9	5.7	6.0	256	136	120
7597B	2345	Ap	8–15	43.2 ± 7.3	-26.2	8.7	0.71	12	31.2	6.2	6.0	238	125	113
7597C	2346	Bw1	20–36	-97.5 ± 4.5	-24.7	3.6	0.40	9	19.1	6.3	6.4	248	107	141
7597D	2347	Bw2	46–56	-176.5 ± 6.4	-25.5	1.7	0.20	9	13.2	6.4	6.4	167	57	110
7597E	2348	BC	74–89	-457.5 ± 5.9	-25.0	1.1	0.15	7	14.2	6.4	6.4	127	50	77

Site 5: Measurements *(Continued)*

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties: Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 mm	% Silt 0.02–0.002 mm	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
7597A		Ap	0–8	0.66		55	23	22	Predominantly: Allophane, volcanic glass, HIV Small amounts of: halloysite	Blank spaces in tables indicate no available data. †CEC = cation exchange capacity; me % = c mol(+) kg^{-1}
7597B	2345	Ap	8–15	0.82		56	26	18		
7597C	2346	Bw1	20–36	0.74		65	26	9		
7597D	2347	Bw2	46–56	0.83		67	21	12		
7597E	2348	BC	74–89	0.85						

Site 10: Location and Soil Description

Soil name: Judgeford Silt Loam — Lab no. SB07536

Site, Soil Descriptions and Analytical Data — Date sampled: 7 Sept. 1959

Latitude:	41°07′S	Longitude:	174°57′		
N.Z. genetic classification:	Yellow-brown earth	NZSC:	Pallic firm brown soil	FAO:	Dystric cambisol
Survey:	Paekakariki	Region:	Hutt County, North Island		
Location:	Judgeford, Abbotts farm - 2.4 km east of Pauatahanui				
Topdressing:	Not known				
Annual rain:	1145 mm	Elevation:	60 m	Mean annual temp:	13°C
Landform:	Ridge of hill in rolling country				
Microrelief:	Flat	Slope:	5° convex crest	Aspect:	270°
Slope movement:	Creep mantle	Topsoil loss:	Not known		
Drainage:	Moderately good	Land use:	Long-term grass		
Improvements:	Ploughed				
Vegetation:	Browntop, Yorkshire fog, Cocksfoot, Bracken fern				
Parent materials:	Moderately weathered loess from greywacke plus volcanic ash				
Notes:					

Horizon	Depth (cm)	Horizon description
Ap1	0–8	Dark greyish brown (10YR 4/2) silt loam; moderately weak soil strength; moderately developed fine granular structure; no mottles; many live roots; many fine cast granules; indistinct boundary.
Ap2	8–23	Brown to dark brown (10YR 4/3) silt loam; moderately weak soil strength; moderately developed fine nut structure; no mottles; many live roots; some fine cast granules; indistinct boundary.
Bw	23–43	Dark yellowish brown (10YR 4/4) silt loam; moderately firm soil strength; moderately developed fine nut structure; no mottles; many live roots; distinct boundary.
Bw(f)	43–53	Dark yellowish brown (10YR 4/4) & light olive brown (2.5Y 5/4) silt loam; moderately firm soil strength; weakly developed fine blocky breaking to massive structure; many coarse dark brown (7.5YR 3/2) mottles; no live roots; indistinct boundary.
BC(f)	53–74	Light olive brown (2.5Y 5/4) silt loam; moderately firm soil strength; weakly developed medium blocky structure; many fine strong brown (7.5YR 5/6) mottles; no live roots; indistinct boundary.
Cu	74–80+	Light olive brown (2.5Y 5/4) silt loam; moderately firm soil strength; massive; no mottles; no live roots.

Site 10: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties								
				$\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	C %	N %	C/N	CEC* me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
7536A	2352	Ap1	0–8	−34.9 ± 6.8	−27.5	7.1	0.48	15	19.9	4.5	5.9	49	36	13
7536B	2353	Ap2	8–20	−44.0 ± 6.8	−27.1	4.2	0.31	14	15.5	5.4	5.9	35	22	13
7536C	2354	Bw	25–43	−140.2 ± 6.4	−26.0	1.9	0.12	16	10.5	5.4	5.9	24	13	11
7536D	2355	Bw(f)	46–53	−350.0 ± 6.6	−26.1	1.0	0.08	13	8.5	5.6	5.9	28	16	12
7536E	2356	BC(f)	58–74	−457.1 ± 6.1	−24.9	0.7	0.07	10	9.4	5.5	5.6	33	18	15
7536F		Cu	76–94			0.7	0.06	12	6.0	5.3	5.8	45	23	22

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties						
				Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 MM	% Silt 0.02–0.002 MM	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
7536A	2352	Ap1	0–8	0.94		31	33	23	Predominantly: vermiculite	Blank spaces in tables indicate no available data.
7536B	2353	Ap2	8–20	1.05		32	36	32		
7536C	2354	Bw	25–43	1.31		39	33	22		
7536D	2355	Bw(f)	46–53	1.38		41	32	27		* CEC = cation exchange capacity; me % = c mol(+) kg⁻¹
7536E	2356	BC(f)	58–74	1.42		39	34	27	Small amounts of: mica-vermiculite	
7536F		Cu	76–94							

Site 13: Location and Soil Description

Soil name: Okarito Peaty Loam

Lab no. SB07719

Site, Soil Descriptions and Analytical Data

Date sampled: 7 Feb. 1961

Latitude: 42°43′S
Longitude: 170°59′

N.Z. genetic classification: Gley Podzol
NZSC: Peaty-silt-mantled Perch-gley Podzol
FAO: Gleyic podzol

Survey: 1962 Conference site
Region: Westland, South Island

Location: Aerodrome Terrace, Hokotika, 155 m east of south runway

Topdressing: Nil
Annual rain: 2795 mm
Elevation: 30 m
Mean annual temp: 11°C

Landform: Terrace in coastal system
Microrelief: Flat
Aspect:
Slope:
Slope movement: Not known
Topsoil loss: Not known
Drainage: Moderately well
Land use: Unused natural
Improvements: Nil
Vegetation: Blechnum minor, Sedge, Lycopodium, Umbrella fern, Moss
Parent materials: Silty alluvium or loess over greywacke, schist, granite gravels
Notes:

Horizon	Depth (cm)	Horizon description
Oh1	0–10	Dark reddish brown (5YR 3/2) peaty loam; no mottles; sharp smooth boundary.
Oh2	10–30	Dark reddish brown (5YR 3/2) peaty silt loam; slightly sticky; no mottles; distinct boundary.
Er	30–56	Grey (5Y 5/1) silt loam; very firm soil strength; massive; no mottles; many fine live roots; distinct boundary.
bAh	56–84	Dark brown (10YR 3/3) fine sandy loam; moderately firm soil strength; massive; no mottles; few rounded gravels; indistinct boundary.

Site 13: Location and Soil Description *(Continued)*

bEr1	84–97	Weak red (2.5YR 4/2) loamy very fine sand; very firm soil strength; massive; no mottles; indistinct boundary.
bEr2	97–102	Grey (5Y 5/1) loamy very fine sand; moderately firm soil strength; massive; no mottles; indistinct boundary.
2bBh	102–112	Dark brown (10YR 3/3) gravelly sand; loose soil strength; no mottles; many strongly weathered subangular stones.
2bBfm/Cu	112–127	Dark reddish brown (2.5YR 3/4) strongly cemented; no mottles; continuous iron-pan; sandwiching loose gravelly sand. single grain; no mottles; many stones.
3bCu	127–130+	Gravelly sand; loose soil strength; single grain; no mottles; many stones.

Site 13: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties								
				$\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	C %	N %	C/N	CEC* me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
7719A		Oh1	0–8			30.8	1.28	24	66.4	4.1	4.4	58	47	11
7719B	2361	Oh2	13–30	−24.7 ± 6.9	−27.6	19.7	0.59	33	30.8	4.1	4.7	21	10	11
7719C	2362	Er	33–48	−317.0 ± 5.9	−27.9	5.2	0.12	43	15.3	4.7	5.1	14	7	7
7719D	2363	bAh	56–84	−646.6 ± 3.9	−28.0	8.9	0.19	47	27.5	4.9	4.9	36	30	6
7719E	2364	bEr	84–97	−667.8 ± 4.7	−29.2	4.3	0.13	33	15.6	4.8	4.8	24	18	6
7719F	2365	2bBh	102–112	−442.4 ± 5.4	−27.8	4.0	0.09	44	21.2	4.8	5.0	38	9	29

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties						
				Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 mm	% Silt 0.02–0.002 mm	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
7719A		Oh1	0–8	0.38					Predominantly: quartz, mica	Dry bulk density figures for 7719A, B were estimated from 12 Oh horizons with similar carbon contents at similar depths.
7719B	2361	Oh2	13–30	0.38		49	43	8		
7719C	2362	Er	33–48	0.91		56	34	10	Small amounts of: mica-vermiculite, vermiculite, kaolin	
7719D	2363	bAh	56–84	0.76		60	28	12		Mean = 0.38 Std Dev = 0.17
7719E	2364	bEr	84–97	1.03		63	31	6		Blank spaces in tables indicate no available data.
7719F	2365	2bBh	102–112		20	80	15	5		*CEC = cation exchange capacity; me % = c mol(+) kg⁻¹

Site 16: Location and Soil Description

Soil name: Carrick Fine Sandy Loam — Lab no. SB08712

Site, Soil Descriptions and Analytical Data — Date sampled: 19 Nov. 1971

Latitude:	45°27′S	Longitude:	169°13′		
N.Z. genetic classification:	Yellow-brown earth	N.Z.S.C.:	Mottled acid brown soil	FAO:	Dystric cambisol
Survey:	Tussock Grassland Study	Region:	Tuapeka, South Island		
Location:	Top of Waikaia Bush Rd, 370 m below crossing of Boulder Ck branch of Shingle Creek, 6 m from SW side of Rd.				
Topdressing:	Nil				
Annual rain:	1400 mm	Elevation:	1460 m	Mean annual temp:	2°C
Landform:	Hill country				
Microrelief:	Flat	Slope:	10°	Aspect:	45°

Site 16: Location and Soil Description *(Continued)*

Slope movement:	Not known	Topsoil loss:	Not known
Drainage:	Moderately well	Land use:	Rough grazing
Improvements:	Nil		
Vegetation:	*Chionochloa rigida* and *macra*, *Poa colensoi*, Open tussock		
Parent materials:	Moderately weathered Schist		
Notes:	A ? on the "Soil Name" indicates the series name for this profile is tentative, however, all other data is considered to be valid. Hor 3 10YR 4/3. Hor 4 5Y 5/2 –6/2 (Gley areas)		

Horizon	Depth (cm)	Horizon description
Ah1	0–1	Very dark greyish brown (10YR 3/2) silt loam; moderately developed crumb structure; abundant live roots; distinct boundary.
Ah2	1–4	Brown to dark brown (10YR 4/3) silt loam; moderately developed crumb structure; many live roots; indistinct boundary.
Bw	4–9	Yellowish brown (10YR 5/4) silt loam; weakly developed nut plus moderately developed crumb structure; few stones; few live roots; distinct boundary.
Bw(f)	9–20	Light olive brown (2.5Y 5/4) silt loam; weakly developed medium nut structure; faint strong brown (7.5YR 5/6) mottles; weakly weathered schist stones; indistinct boundary.
BC	20–36	Light olive brown (2.5Y 5/4) fine sandy loam; weakly developed blocky structure; yellowish brown (10YR 5/6) coatings; abundant stones.

Site 16: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties								
				$\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	C %	N %	C/N	CEC* me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
		Ah1	0–1											
8712A	4570	Ah2	1–4	85.0 ± 8.6	−25.7	4.9	0.32	15	19.5		4.6	88	65	23
8712B	4571	Bw	4–9	−16.8 ± 3.9	−25.8	3.7	0.21	18	18.8		4.6	71	52	19
8712C	4572	Bw(f)	9–20	−79.2 ± 3.8	−25.8	2.9	0.19	15	18.1		4.7	61	45	16
8712D	4573	BC	20–36	−117.2 ± 3.7	−25.9	2.3	0.16	14	17.5		4.8	57	44	13

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties						Comments
				Dry bulk density (t/m^3)	Stones (% v/v)	% Sand 2.0–0.02 (mm)	% Silt 0.02–0.002 (mm)	% Clay <0.002 (mm)	Clay minerals (topsoil only)	
		Ah1	0–1						Predominantly: mica-vermiculite	Blank spaces in tables indicate no available data. *CEC = cation exchange capacity; me % = c mol(+) kg^{-1}
8712A	4570	Ah2	1–4	0.79						
8712B	4571	Bw	4–9	0.88						
8712C	4572	Bw(f)	9–20	1.03						
8712D	4573	BC	20–36	1.19						

Site 19: Location and Soil Description

Soil name: Tima Silt Loam			Lab no. SB08856
	Site, Soil Descriptions and Analytical Data		Date sampled: 29 Mar. 1973

Latitude:	45°24′S	Longitude:	169°25′		
N.Z. genetic classification:	Yellow-grey earth	NZSC:	Typic Laminar Pallic soil	FAO:	Dystric Cambisol
Survey:	Tussock Grasslands	Region:	Tuapeka, South Island		
Location:	Top of Knobby Range Rd. 20 km NE of Roxburgh; Roadside reserve				
Topdressing:	Nil				
Annual rain:	625 mm	Elevation:	750 m	Mean annual temp:	8°C
Landform:	Ridge				
Microrelief:	Flat	Slope:	0° concave	Aspect:	292°
Slope movement:	Not known	Topsoil Loss:	Not known		
Drainage:	Moderately well	Land use:	Rough grazing		
Improvements:	Nil				
Vegetation:	Lowland tussock grassland, *Festuca novae-zelandia, Chionocloa rigida, Poa colensoi.*				
Parent materials:	Weakly weathered schist loess over schist bedrock.				
Notes:	A ? on the "Soil name" indicates that the series name for this profile is tentative; however, all other data is considered to be valid. Fragipan+drainage semi-impermeable. Erosion slight; topsoil loss in past, nil now. Microfeatures = exhumed tor landscape. Hor 1 few casts. Hor 2 many abundant casts. Hor 3 +5y5/2 with some nut structure, common casts. Hor 4 +2.54/4, very few casts, few fine Fe mottles, rare clay skin. Hor 5 +5y6/2 matcol.				

Horizon	Depth (cm)	Horizon description
Ah1	0–13	Dark greyish brown (10YR 4/2) fine sandy loam; moderately developed medium nut plus crumb structure; many live roots; indistinct boundary.
Ah2	13–22	Dark greyish brown (10YR 4/2) fine sandy loam; moderately developed medium plus coarse nut structure; common live roots; indistinct boundary.
Bw(f)	22–32	Dark greyish brown (2.5Y 4/2) fine sandy loam; weakly developed moderately developed coarse blocky structure; many medium faint dark yellowish brown (10YR 4/4) mottles; few live roots; indistinct boundary.
BCx	32–50	Olive grey (5Y 5/2) fine sandy loam; weakly developed coarse prismatic plus moderately developed coarse blocky structure; few fine mottles; few live roots; distinct boundary.
Cu	50–70	Pale yellow (5Y 7/3) sandy loam; massive.

Site 19: Measurements

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Isotopes		Chemical Properties									
				$\Delta^{14}C$ ‰	$\delta^{13}C$ ‰	C %	N %	C/N	CEC† me %	pH (H_2O) dry soil	pH (H_2O) moist soil	Total P mg %	Org. P mg %	Inorg. P mg %
8856A	4533	Ah1	0–13	145.0 ± 4.4	-26.2	2.3	0.19	12	11.1		5.9	89	38	51
8856B	4534	Ah2	13–22	14.8 ± 3.5	-26.3	1.7	0.15	11	11.4		6.2	81	42	39
8856C	4535	Bw(f)	22–32	–46.9 ± 5.3	-24.8	1.0	0.09	11	9.5		6.1	54	31	23
8856D	4536	BCx	32–50	-264.4 ± 6.7	-26.2	0.6	0.06	10	9.8		6.1	53	26	27
8856E	4537	Cu	50–70	-378.8 ± 6.3	-26.0	0.2	0.02	*	5.1		6.2	67	8	59

Site 19: Measurements *(Continued)*

S.B. lab no.	N.Z. lab no.	Horizon desig.	Sample depth (cm)	Physical–Mineralogical Properties: Dry bulk density t/m³	Stones (% v/v)	% Sand 2.0–0.02 mm	% Silt 0.02–0.002 mm	% Clay <0.002 mm	Clay minerals (topsoil only)	Comments
8856A	4533	Ah1	0–13	1.12	0	61	20	19	Predominantly: mica	Blank spaces in tables indicate no available data.
8856B	4534	Ah2	13–22	1.25	0	59	22	19		
8856C	4535	Bw(f)	22–32	1.45	0	56	24	20	Small amounts of: mica-vermiculite, mica-HIV, kaolin	*C/N ratio not calculated where N <0.05.
8856D	4536	BCx	32–50	1.69	0	58	21	21		†CEC = cation exchange capacity; me % = c mol(+) kg^{-1}
8856E	4537	Cu	50–70	1.47	0	72	24	4		