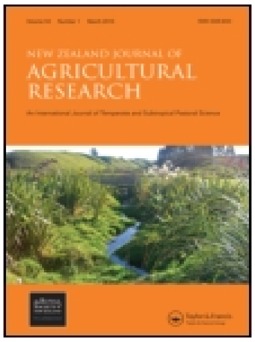

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THE DISTRIBUTION OF MOLYBDENUM IN THE SOILS OF NEW ZEALAND

I. SOILS OF THE NORTH ISLAND

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(*Received for publication, 12 August 1959*)

Summary

Soils of the North Island have been examined for their molybdenum content. Wide variations in levels of molybdenum extracted by acid ammonium oxalate have been found for individual soil sets, but some important differences are noticeable between genetic soil groups.

Total molybdenum levels in certain North Auckland soil suites are shown to decrease as the soils become more leached.

In a comparison of sedimentary rocks, mudstones give soils higher in acid-oxalate-soluble molybdenum than do sandstones or greywackes. In the volcanic and igneous groups, yellow-brown loams from andesitic and rhyolitic ash are generally much higher than yellow-brown pumice soils from rhyolitic ash. Immature basalt soils have high levels of available molybdenum.

Some correlations have been shown with the type of clay minerals in the soils.

Response of pasture to molybdate topdressing has been discussed in relation to the different soil groups.

A comparison of soil test levels and pasture responses has shown that acid ammonium oxalate is not reliable for diagnosing deficiencies in that it extracts a portion of the iron-bound molybdate which would not be available to plants.

Introduction

Following early indications (Davies *et al.* 1951; Lobb 1953) that remarkable improvements in pastures and crops would be obtained by the application of small quantities of molybdenum, a concentrated programme of research has been undertaken by officers of the Extension Division, Department of Agriculture, to study its place in the farming economy of New Zealand. As part of this programme, a survey was made of the molybdenum content of New Zealand soils to define those areas where molybdenum would be a useful auxiliary fertiliser.

Early studies showed that levels of total soil molybdenum did not correlate well with field responses, and a method of extracting a readily soluble fraction of the soil molybdenum was devised (Grigg 1953a, b, c). This method is based on the replacement of molybdate held on the clay complex as an exchangeable anion by oxalate from an acid ammonium oxalate solution of pH 3.3.

A large number of analyses for acid-oxalate-soluble molybdenum has accumulated, and it is the purpose of this paper to classify these and if possible to draw some general conclusions from the levels found.

* This work was carried out while the author was at the Rukuhia Soil Research Station, Hamilton.

Total molybdenum levels have been determined by the method of Perrin (1947) for a few soils in North Auckland and these are also discussed briefly.

ORIGIN OF SAMPLES

Soil samples have been collected from three sources:

(1) From molybdenum topdressing trials, mainly on pasture, as they were laid down. Soil types have been checked by officers of the New Zealand Soil Bureau.

(2) From farms in connection with the Extension Division Advisory Soil Testing Service. These samples were collected by field officers of the Division who have a sound knowledge of the soils of their own district.

(3) From the Superintendent, Wallaceville Animal Research Station. Samples were collected from defined soil types in company with Soil Bureau officers in carrying out a survey of the copper and molybdenum content of pastures (Cunningham *et al.* 1956).

Most samples of soil under pasture have been taken to a 3 in. depth. Some samples from arable ground have been 0–6 in., and a few Soil Bureau samples have been from the A horizon of an undisturbed profile.

METHOD OF PRESENTATION OF RESULTS

A classification of the soils with emphasis on parent material has been selected as the most suitable for the purpose of this paper. Such a scheme is in use by the Department of Agriculture for coding results of advisory soil tests on Powers Samas punch cards, and is used here with modifications. An attempt has been made to separate, where possible, the effects of weathering and leaching.

Basic soil data have been taken from Soil Bureau Bulletin 5, "General Survey of the Soils of North Island, New Zealand", from the Genetic Soil Map of New Zealand (Taylor 1948), and from other more detailed local soil surveys.

Analytical results are considered in suites of soils derived from the same or similar parent material, where possible, in the divisions given below. Taylor's (1948) genetic group numbers are shown in parentheses. Skeletal soils are included with their nearest zonal counterpart.

(1) Soils derived from sedimentary and acid igneous rocks:

Rendzinas	(11)
Yellow-grey earths	(2b, 2f, 2h)
Yellow-brown earths and podzols	(5a–5c, 6a–6c, 7a, 7b)
Yellow-brown sands	(12)

(2) Soils derived from volcanic ash and basic igneous rocks.

This includes the following groups:

Recent soils from volcanic ash	(20b)
Yellow-brown pumice soils from rhyolitic ash	(13a, 13b)
Yellow-brown loams from rhyolitic and andesitic ash	(14a–14d)
Brown granular loams and clays from volcanic ash and from andesite	(15a, 15b)
Red-brown loams from basalt	(16a–16c)

(3) Soils of the plains:

Recent soils from alluvium	(20a)
Gley soils	(17)
Saline gley soils	(18)
Organic soils	(19)

In order to give a detailed picture of the range and distribution of molybdenum levels for the subdivisions concerned, the mean (M) and its standard deviation (S) have been listed. The interval M $\pm$ S includes about ⅔ of the samples in the group.

The number of samples within various ranges of molybdenum content are also given to show the distribution of values.

TOTAL MOLYBDENUM LEVELS

On certain parent rocks in the North Auckland district it has been possible to map suites of soils of varying degree of development, reflecting the formation of the soils under an original environment of mull-forming, mor-forming, or mixed forest. The results in Table 1 show that there is a progressive loss of molybdenum as leaching and podzolisation proceed. This is very marked for the Omu, Marua, and Te Kie suites, in the levels of both total and acid-oxalate-soluble molybdenum, but is not so marked in the Puhoi suite where the sandstone parent material is low in molybdenum at all stages of development.

The few examples from the Kiripaka suite of soils formed on basalt illustrate a different mechanism of soil formation. As pointed out by Taylor *et al.* (1956), weathering is the dominant factor on this parent material, leading to accumulation of sesquioxides rather than podzolisation. The total molybdenum levels found are in agreement with figures given by Wells (1956) who showed that the youngest members of the sequence had very high molybdenum levels, the semimature members had lower amounts, while the mature members with ironstone nodules again contained higher amounts, reflecting the tendency of molybdenum to accumulate with sesquioxides.

AVAILABLE MOLYBDENUM LEVELS AS MEASURED BY OXALATE SOLUBILITY

Soils Derived from Sedimentary Rocks and Acid Igneous Rocks

Table 2 lists these soils for the North Auckland district and Table 3 for the rest of the North Island. This separation is made because the North Auckland soils can be classified into suites of soils, each on one type of parent material, more completely than can the soils for the rest of the Island.

North Auckland Soils. Soils from parent materials containing limestone in North Auckland are predominantly below 0.10 p.p.m., although a few high values raise the mean to 0.15 p.p.m.

On coastal sand dunes recently fixed by vegetation (Pinaki suite), very low molybdenum levels are found. As the dunes consolidate and weather (immature and semimature stages), higher levels are found, especially on the sandy loams and sandy clay loams, but, as podzolisation occurs, exceedingly low levels are again reached.

In the Omu suite (claystone) there is a progressive reduction in molybdenum levels with maturing of the soil as was mentioned earlier. Although only 3 samples represent the young and immature stages, the trend is quite marked.

Puhoi and Waiotira suites from sandstone show that even the least leached members (skeletal to immature stages) have low levels of molybdenum. There is nevertheless a decrease in the submature and mature stages of the Waiotira suite.

Soils of the Marua suite, which are derived from greywacke, are also low to very low in molybdenum. Here again the two samples of the submature member (Hukerenui silt loam, yellow subsoil phase, Hr) are exceedingly low.

Other North Island Soils. Results for the rest of the North Island in Table 3 show many interesting features.

Yellow-grey earths from alluvium, muddy sandstone, etc., are generally high in molybdenum, reflecting the higher initial molybdenum content and the lower degree of leaching of these soils. Yellow-grey earths in the South Island*, in contrast, are very low in molybdenum. The group classed as yellow-grey earths transitional to yellow-brown earths gives much lower levels than North Island yellow-grey earths and slight responses have been obtained on some of these types.

The yellow-brown earth to podzol sequences are subdivided according to whether the parent material is predominantly limestone, sand, mudstone, sandstone, or greywacke. Complexes of these with volcanic ash are considered later in the table.

The coastal dune sand soils are similar to those in North Auckland. Where there is admixture of volcanic ash or pumice much higher levels of molybdenum are found.

In the mudstone group, the mean for skeletal soils is very high. Young and immature soils show lower values, but the three groups overlap.

As in North Auckland, soils derived from sandstone are lower than those from mudstone, but the skeletal group here is higher than in the Puhoi and Waiotira suites.

Soils formed on greywacke tend to be slightly higher than soils of the Marua suite in North Auckland and there is no noticeable diminution of level with greater degree of leaching.

A subdivision of those soils where volcanic ash is present shows a similar situation, molybdenum levels in mudstones being little affected by the ash, whereas in sandstones and greywackes the mean levels are higher.

The Takapau suite of soils from sandstone and greywacke alluvium with pumiceous ash gives mean values very similar to the complexes of ash with sedimentary rocks.

* Molybdenum status of South Island soils will be dealt with in Part II of this series.

Soils Derived from Volcanic Ash and from Intermediate and Basic Volcanic Rocks

As will be seen from Table 4 the mean content of oxalate-soluble molybdenum in these soil groups is in general much higher than in the sedimentary rocks.

The pumice soils of the central plateau region are in general well supplied with molybdenum. Some members of the Taupo and Kaharoa suites give low figures. The reason for this may lie in the fact that these soils are lighter in texture.

An area of an early phase of the Taupo ash shower north of Wairoa has been entered separately because of much higher molybdenum levels found both in the soil and the pasture (Cunningham 1955).

Yellow-brown loams formed from the Waihi and Tirau showers of rhyolitic ash have higher levels of available molybdenum than any other soil group (apart from a few samples examined in the Kiripaka suite). Levels as high as 1.5 p.p.m. have been obtained on Katikati sandy loam (soil set 54). These results agree with Wells' (1956) finding that yellow-brown loams have a high retentive power for molybdate.

Andesitic showers in the western districts of the North Island from Raglan to Wanganui give rise to soils having molybdenum levels which, while still high, are considerably lower than those of the Waihi and Tirau suites.

The brown granular clays of the Hamilton ash suite present some interesting features. Soils classed as Hamilton clay loam (83) fall into two distinct groups. In the Hamilton area they ranged from 0.54 to 1.42 while in the Franklin County the levels were 0.15 to 0.27 p.p.m. Other soil sets derived from Hamilton ash ranged in molybdenum content from 0.09 to 0.33 p.p.m. with the exception of Patumahoe clay loam (82- Hamilton ash over basalt and sediments) which gave very high figures (0.35–0.65 p.p.m.). Grouping these soils together results in a bimodal frequency distribution.

Additional evidence for differences in Hamilton ash between the two localities mentioned is found in the soil potassium levels (Rukuhia Soil Research Station, unpublished data).

In contrast to the high levels found in the yellow-brown loams and brown granular loams and clays derived from andesitic ash, the brown granular loams and clays of North Auckland, derived from andesitic breccias and andesitic basalt, etc., are considerably lower in molybdenum. This difference may be connected with the kaolinitic nature of this latter group of brown granular clays, whereas in yellow-brown loams the predominant clay minerals are amorphous hydrous oxides of iron and aluminium and allophane, (Fieldes and Williamson 1955).

Young and immature soils from basalt (Ohaeawai silt loam and Whatatiri clay loam) are listed separately as they give very high levels of available molybdenum. The semimature and mature members of the suite are very low, even though their total molybdenum content may be very high (cf. Table 1). These figures again confirm Wells' (1956) finding that weakly leached basalt soils have a high retentive power for molybdate while strongly leached members of the suite have a lower retention, in agreement with the changing of the amorphous hydrous oxides of aluminium, iron, and titanium into fine crystals of gibbsite, goethite, boemite, and anatase (Fieldes and Williamson 1955).

Alluvial, Saline, and Organic Soils

Although there are some low values, the majority of soils in this group are also well provided with molybdenum, as will be seen from Table 5. Gley soils derived from volcanic-ash alluvium are much higher in oxalate-soluble-molybdenum than those derived from alluvium from sedimentary rocks. It is not possible to divide the recent alluvial soils into those from sediments and those from ash with any degree of certainty owing to the incomplete differentiation of recent soils in the general survey.

The saline-soil samples are mainly from the Ahuriri lagoon reclamation area. High levels of pasture molybdenum here cause stock trouble.

It is not known whether the acid-oxalate extraction gives a true picture of molybdenum solubility on organic soils. Molybdenum may be present in them as an organic complex, not an exchangeable anion, and hence fail to be removed by the oxalate solution.

RESPONSE OF PASTURES TO MOLYBDATE TOPDRESSING

At the right of Tables 2, 3, 4, and 5 an assessment has been given of the degree of response obtained in Extension Division field experiments with molybdenum, applied either as sodium molybdate or as molybdenised superphosphate. Where sodium molybdate was used basal superphosphate treatments have been applied in all cases. These data have been obtained from Extension Division records and from published articles (Clarke *et al.* 1957a, b).

The main soil groups on which responses have been obtained are:

(1) Zonal soils formed from sandstone (Omanaia, Puhoi, Waiotira suites) and greywacke (Marua suite), more especially the skeletal to semimature members of these sequences. Such areas are widespread in North Auckland, Raglan County, and in the Wellington and southern Hawke's Bay districts. The submature and mature members, however, give only slight responses easily masked by liming.

(2) Soils formed from mudstones and claystones. In the Omu suite (North Auckland) responses are not obtained on the young and immature members nor on the mature soil, but slight to good responses are obtained for the intermediate members. In the rest of the North Island responses occur only on the immature soils.

(3) Slight responses have been obtained on immature to mature soils formed on consolidated dune sands.

(4) Responses are fairly general on the brown granular loams and clays derived from andesitic rocks in North Auckland. This is in contrast to the brown granular loams and clays from andesitic ash and may be due to a kaolinitic type of soil clay in these soils.

(5) Mature members of the red-brown loams formed from basalt (Kiripaka suite) in North Auckland, which also have a more crystalline form of soil clay.

No responses have been recorded on the following groups of volcanic ash soils:

Yellow-brown pumice soils
Yellow-brown loams
Brown granular loams and clays from volcanic ash.

Although data are meagre, no responses have been recorded on soils derived from limestone and calcareous mudstones.

Recent and gley soils formed from alluvium from either sedimentary rocks or volcanic ash have given no responses.

RELATION BETWEEN SOIL MOLYBDENUM LEVELS AND GROWTH RESPONSE OF PASTURE

In general, those soils giving molybdenum responses have levels of acid-oxalate-soluble molybdenum below 0.20 p.p.m., although not all soils with lower levels have given responses.

Non-responsive soils generally have higher levels, the bulk of samples being greater than 0.15 p.p.m.

In an earlier paper (Grigg 1953a) a tentative response level of 0.14 p.p.m. was suggested, but as more trial results have been obtained it has become apparent that soil type is a better guide to molybdenum response than the chemical test.

It has been postulated that available molybdenum exists as an exchangeable anion (Grigg 1953; Davies 1956). The acid-ammonium-oxalate extraction was developed on the hypothesis that absorbed molybdate would be replaced and complexed by oxalate ions. However, at the reaction chosen (pH 3.3) this reagent dissolves considerable amounts of iron and aluminium oxides.

Wells (1956) considers that hydrous oxides of iron and aluminium formed in the soil by weathering have a high retentive power for the molybdate ion and that this accounts for the low availability of molybdenum in these soils. Jones (1957) has also shown that hydrous ferric oxide has a great adsorptive power for molybdate.

Williams and Moore (1952) showed that the uptake of molybdenum by oats varied directly with the soil reaction, but inversely with the content of ferric iron in the soils, i.e. hydroxyl ions tend to liberate molybdate while iron tends to render it unavailable.

It would thus appear that the acid-ammonium-oxalate extractant dissolves not only the exchangeable molybdate fraction, but also some of the ferric molybdate which would not be available to the plant.

Ammonium oxalate solutions of the same ionic strength (0.275 M) but different pH levels were examined on some zonal soils and intrazonal soils from volcanic ash. Results showed that the neutral solution extracted 27–97% of the amount dissolved by the acid solution on volcanic-ash soils. On zonal soils, however, which would not be expected to have high contents of hydrous iron oxides, the amount extracted was approximately the same with both solutions.

DISCUSSION

Since most of the samples are classed in sets, defined as "groups of soils of like profiles or assemblages of profiles", (N.Z. Soil Bureau Bull. 5, 1954), the wide range of values obtained in individual sets is not unexpected. More precise classification into soil types was not possible for this work.

The levels obtained support the pattern of conditions for molybdenum excess and deficiency postulated by various workers and reviewed by Davies (1956).

It is considered that the publication of these accumulated figures may assist in focussing attention on areas where more experimental work is required.

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TABLE 1. TOTAL AND ACID OXALATE SOLUBLE MOLYBDENUM LEVELS FOR SOME INDIVIDUAL SAMPLES OF NORTH AUCKLAND SOIL TYPES

Soil Suite and Type	Stage of Development	Total Mo p.p.m.	Acid Oxalate Soluble Mo p.p.m.
Yellow-brown earth to podzol sequences			
Omu Suite (Claystone, shale, etc.)			
Aponga clay	Immature-early semimature	4.0	0.29
Waikare brown clay	Semimature-submature	2.0	0.16
Hukerenui silt loam	Submature	1.1	0.10
Wharekohe silt loam	Mature	0.8	0.04
Puhoi Suite (Banded sandstone)			
Atuanui clay loam	Skeletal	0.8	0.08
Puhoi clay loam	Young-immature	1.3	0.12
Whangaripo clay loam	Immature-early semimature	1.1	0.09
Warkworth clay	Semimature	0.9	0.05
Marua Suite (Greywacke)			
Te Ranga clay loam	Skeletal	2.2	0.18
Marua clay loam	Immature-early semimature	1.2	0.11
Rangiora silty clay loam	Semimature	1.0	0.13
Hukerenui silt loam (yellow subsoil phase)	Submature	1.3	0.07
Pinaki Suite (Dune sands)			
Pinaki sand	Young-immature	2.0	0.04
Red Hill sand	Immature-early semimature	1.5	0.04
Te Kopuru sand	Mature	0.9	0.08
Brown granular loam to podzol sequence			
Te Kie Suite (Doleritic breccias & tuffs)			
Te Kie stony loam	Skeletal	3.1	0.20
Takitu clay loam	Young-immature	2.0	0.12
Waimatenui clay	Semimature	2.0	0.11
Awarua clay	Later semimature	2.0	0.09
Rangiuru clay	Later semimature	1.9	0.07
Tinopai sandy loam	Mature	1.8	0.12
Red-brown loam to ironstone soil sequence			
Kiripaka Suite (Basalt)			
Whatatiri clay loam	Young-immature	4.6	1.11
Matarau friable clay	Semimature	1.3	0.03
Okaihau gravelly friable clay*	Submature-mature	6.7	0.08

* Subsoil sample containing ironstone nodules in which molybdenum is known to concentrate.

TABLE 2. ACID OXALATE SOLUBLE MOLYBDENUM LEVELS OF NORTH AUCKLAND SOILS FROM SEDIMENTARY AND ACID IGNEOUS ROCKS

Parent Material	Suite	Stage of Development †	Soil Types *	Mean (p.p.m.)	S.D.	No. of samples with Mo Level (p.p.m.) from				Response of pasture to molybdate topdressing
						0–.10	.11–.20	.21–.30	>.30	
Limestone	Arapohue	—	AU, MT	0.15	0.09	8	3	3	1	No information
Limestone and mudstone	Maungaturoto	—	MO, MK, D							
Limestone, mudstone, and sandstone	Konoti	—	KN							
Calcareous mudstone	Whaka	S	RV							
Coastal sand dunes	Pinaki	Y–I	PN, WH, MD	0.07	0.04	8	1	—	—	PN—Nil
		I–ES	R, Rs, Rl, Rc	0.13	0.05	4	8	2	—	R, Rl—Slight
		M	TK	0.03	0.02	16	—	—	—	Slight
Claystone, shale, etc.	Omu	Y–ES	OM, AP	0.37	0.11	—	—	1	2	AP—doubtful
		S	MA, OA	0.15	0.07	2	8	2	—	No information
		S–SU	YK	0.13	0.08	12	10	3	1	Good unless limed heavily
		SU	H	0.08	0.03	9	1	—	—	Slight unless limed heavily
		M	WK	0.06	0.05	7	1	—	—	No response on limed soils
Sandstone and mudstone	Omanaia	Y–ES	WN, ON, AE	0.15	0.07	1	3	1	—	Excellent

Banded sandstone	Puhoi	SK–I	AN, OI	0.09	0.02	8	3	—	—	Excellent
		I–ES	WR	0.10	0.02	16	12	—	—	Excellent
		S	WA	0.08	0.04	10	2	—	—	Good unless heavily limed
Massive sandstone	Waiotira	SK	WC	0.08	0.00	2	—	—	—	No information
		I–ES	Y, Yr, Ye	0.10	0.03	10	6	—	—	Good
		S	RP	0.10	0.03	4	2	—	—	Good
		S–SU	YKs	0.12	0.04	4	8	—	—	Good to excellent
		SU	Hs	0.07	0.04	4	2	—	—	Slight to good; but ceases at moderately high pH
		M	WKs	0.03	—	1	—	—	—	Probably responds if unlimed
Greywacke	** Marua	SK	TR	0.14	0.04	2	8	1	—	Excellent
		I–ES	MR	0.14	0.05	4	10	3	—	Good
		S	RA	0.12	0.04	4	6	—	—	Excellent
		SU	Hr	0.06	0.02	2	—	—	—	Good
Dacite	Maungarei	SK	PE	0.16	—	—	1	—	—	No information
		M	PR	0.11	0.05	1	1	—	—	Fair
Terraces from alluvial sediments	Whareora	I–ES	WO	0.09	—	1	—	—	—	Nil
	Waipu	Gley	YU	0.11	0.04	2	3	—	—	Nil

† Stage of development: SK—Skeletal; Y—Young; I—Immature; ES—Early semimature; S—semimature; LS—Late semimature; SU—submature; M—mature.

* Code letters used in North Auckland Soil Survey. See table 6.

** Includes soils of this suite South of Auckland.

TABLE 3. ACID OXALATE SOLUBLE MOLYBDENUM LEVELS OF SOILS FROM SEDIMENTARY AND ACID IGNEOUS ROCK, NORTH ISLAND EXCLUDING NORTH AUCKLAND

Soil Group and Parent Material	Stage of Develop-ment †	Soil Sets *	Mean (p.p.m.)	S.D.	No. of samples with Mo level (p.p.m.) from					Response of pasture to molybdate topdressing
					0–.10	.11–.20	.21–.30	.31–.40	> .40	
Y.G.E.**										
Alluvium, muddy sandstone etc.	—	8–9b	0.30	0.14	1	1	1	3	1	Nil
Y.G.E. transitional to Y.B.E.										
1. Sandstone and pumiceous sandstone	—	11, 11b, 11c	0.17	0.09	2	3	2	—	—	11 Probable slight response 11b, 11c Probably no response
2. Alluvium	—	11d, 12, 13, 13a	0.10	0.05	10	12	—	—	—	Slight
3. Sandy mudstone and mudstone	—	13b, c, d	0.12	0.05	21	25	2	—	—	13b and c. Variable, slight to good.
Y.B.E. and Podzols										
1. Limestone	SK	113, 113b	0.15	0.07	2	1	2	—	—	Nil
2. Dune sand	Y	23, 23b, 23c	0.08	0.05	35	6	2	—	—	Nil
Weathered sand plus volcanic ash	I	24 to 24d	0.23	0.14	3	6	4	3	2	Variable. Good response on 24d
3. Mudstones, argillites etc.	SK	114, a, b, d, 115a, 120, 121d	0.28	0.14	7	29	11	11	11	Nil
	Y	25a, c, 26a	0.25	0.11	3	8	8	10	1	Nil
	I	28, cH, 29, f, 31d	0.19	0.13	7	17	7	3	2	28. 29 respond

4. Sandstones	SK	116, b, 117, b, c, 118a	0.17	0.09	9	14	2	4	—	118a, Possible response
	I	32c	0.10	0.05	5	3	—	—	—	Nil
	S	34a, 34b	0.09	0.05	13	8	2	—	—	34b good, 34a doubtful
5. Greywacke	SK	122, 124, b	0.14	0.07	11	16	4	—	—	All greywacke derived soils respond
	S	35a, bH, 41aH, b	0.16	0.08	4	9	3	1	—	
	LS–SU	44c, 46, d	0.15	0.07	6	8	3	—	—	
Y.B.E. Complexes with volcanic ash										
1. Mudstone and ash	SK	114c, 115b	0.25	0.12	—	6	6	3	1	
	Y	25, b	0.21	0.09	2	8	6	4	—	No responses have been recorded on this group of soils
	I	29a, c, dH	0.19	0.07	4	12	4	2	—	
2. Sandstone and ash	SK	117d, 117h	0.25	0.16	1	3	—	2	1	
	I	32H, 32b	0.13	0.03	1	3	—	—	—	
3. Greywacke and ash	SK	122a, 125, 125a	0.16	0.06	1	6	2	—	—	
	LS–SU	44dH, 46CH	0.17	0.05	—	4	1	—	—	
Y.B.L. from sandstone and greywacke alluvium plus pumiceous ash	I	74a–76c	0.19	0.08	8	17	22	4	—	No responses of 74 and 75 series
(Takapau suite)	S	77–78b	0.19	0.09	7	10	12	3	1	Variable responses on 76 and 77 series

Notes: † See footnote to table 2 for key to abbreviations.
* Soil set numbers as in Soil Bureau Bull. 5.
** Y.G.E. = Yellow-grey earths; Y.B.E. = Yellow-brown earths; Y.B.L. = Yellow-brown loams.

TABLE 4. ACID OXALATE SOLUBLE MOLYBDENUM LEVELS OF SOILS DERIVED FROM VOLCANIC ASH AND INTERMEDIATE AND BASIC IGNEOUS ROCKS

Soil Groups and Parent Materials	Stage of Development †	Soil Sets *	Mean (p.p.m.)	S.D.	No. of samples with Mo level, p.p.m. from					Response of pasture to molybdate topdressing
					0–.10	.11–.20	.21–.30	.31–.40	>.40	
Recent soils from volcanic ash	—	3, a, 5, a, b, c, e	0.29	0.14	2	2	5	4	3	No information
Soils from Rhyolitic Ash										
1. Yellow-brown pumice soils										
Kaharoa ash	I–SU	14–14c, 15, 16, a, b, 17	0.21	0.10	7	27	21	5	2	No responses have been recorded on soils derived from rhyolitic ash
Taupo ash	I–SU	18 a, b, g, 19–19g, 20, d, e	0.14	0.06	19	33	5	3	—	
Taupo ash, early phase, north of Wairoa	I–S	18, xa, xg, 19x	0.32	0.10	—	2	6	4	3	
Gisborne ash	I–S	21, a, 22, 49, b	0.26	0.09	1	7	9	6	1	
2. Yellow-brown loams										
Whakatane ash	I	51, 51a	0.23	0.16	—	6	2	—	1	
Waihi ash	I–LS	54, a, 55, 56a	0.50	0.29	1	2	7	4	18	
Tirau ash	I–S	57, 57a, 58	0.57	0.38	—	—	—	7	6	
Soils from Andesitic ash										
1. Yellow-brown Loams										
Mairoa and Maihiihi ash	I–LS	59, a, b, c, 60–60f, 61–61d, 62–62b, 63, 64	0.29	0.19	4	12	18	15	6	No responses recorded on soils derived from andesitic ash
Tongariro ash	S	65, 65b, 65c	0.23	0.13	2	6	6	1	1	
Egmont ash	I–S	66, 66d, 67, 67a	0.31	0.12	—	3	11	6	3	
Stratford and Burrell ash	I–LS	66b, 67b, 68, 69, 70, 70a, 71	0.29	0.12	2	5	9	3	8	
Water sorted ash (Waitemata suite)	I–LS	72, 72a, 72b, 73, 73b	0.19	0.11	6	14	13	3	1	
Rhyolite alluvium and andesitic ash (Horotiu suite)	I	48, 48a, 48b	0.39	0.20	—	3	1	2	4	

2. Brown granular loams and clays										
Water sorted ash (Orere suite)	S	81, 81a,	0.28	0.05	—	—	3	1	—	
Hamilton ash	I–S	82, a, b, 83, b, c, 84 a–d	0.37	0.31	3	15	6	5	13	
Hamilton ash complexes with YBE	—	85a, b, 86–86c	0.16	0.08	8	11	12	1	—	
Soils from Intermediate and Basic Igneous Rocks										
1. Brown granular loams and clays										
Andesitic breccias (Huia suite)	SK–S	HA, YT	0.15	0.04	—	4	—	—	—	No information
Doleritic breccias (Te Kie suite)	SK–M	TE, TU, A, YN, AW, RU, TP	0.11	0.04	9	12	1	—	—	TE, YN, AW, RU—excellent; TU, A, TP no trials
Andesitic flows (Katui suite)	Y–LS	KT, WT, TO, AR	0.14	0.06	4	10	1	—	—	WT excellent; KT, TO, AR no trials but response probable
Alluvium from andesitic basalt (Kohumara suite)	Y–LS	M, KM, P	0.13	0.07	2		1	—	—	M good; KM, P, excellent
2. Complexes with sedimentary rocks										
Andesites and dolerites (Haunga, Kaimaro and Parau suites)	I–LS	OB, PA, DV, HH	0.14	0.07	3	9	1	—	—	OB fair; PA, DV, HH, no information.
3. Red-brown loams										
Basalt flows (Kiripaka suite)	Y–I	OH, WI	0.64	0.40	—	—	—	1	2	No information
	S–M	MC, KE, RT, OK	0.08	0.04	7	3	—	—	—	MC no trials; KE, RT, OK, very slight

† * Code symbols and abbreviations as in previous tables.

TABLE 5. ACID OXALATE SOLUBLE MOLYBDENUM LEVELS OF RECENT, GLEY AND ORGANIC SOILS

Soil Group	Soil Sets	Mean (p.p.m.)	S.D.	No. of samples with mo levels (p.p.m.) from					Responses of pasture to molybdate topdressing
				0–.10	.11–.20	.21–.30	.31–.40	> .40	
Recent soils from alluvium:	1, a, b, c, 2, 2a	0.25	0.15	5	31	24	10	9	Responses do not occur on these soils
Recent soils from alluvium, with peat	2b	0.43	0.28	1	1	1	1	3	
Gley soils with moderate natural drainage:									
Alluvium from volcanic ash	98, a, c, d, 100	0.38	0.19	—	1	1	5	4	Responses do not occur on these soils
Gley soils with poor natural drainage:									
Alluvium from volcanic ash	103, c, d, 104a, b, 105a	0.33	0.14	—	2	5	3	3	
Alluvium from sedimentary rocks	101, b, c, d	0.20	0.17	5	11	7	—	1	
Saline gley soils	111, c, 112	0.41	0.29	—	1	1	1	2	
Organic soils:									
Mellow and intermediate peaty loams	107, 107c-f, 108, a, b, 109, b	0.34	0.25	2	6	3	2	5	
Acid peats	110	0.10	0.08	3	1	1	—	—	One response recorded

TABLE 6. PARTIAL KEY TO CODE LETTERS USED IN NORTH AUCKLAND SOIL SURVEY

Suite	Parent Material	Symbol	Soil Type
Arapohue	Limestone	AU	Arapohue clay
		MT	Motatau clay
Maungaturoto	Lime + mudstone	MO	Maungaturoto clay complex
		MK	Matakohe clay complex
		D	Dairy flat complex
Konoti	Limestone + mudstone + sandstone	KN	Konoti clay loam
Whaka	Calcareous mudstone	RV	Rockvale clay
Pinaki	Sand	PN	Pinaki sand
		WH	Whananaki sand
		MD	Marsden sand
		R	Red Hill sandy loam
		Rs	Red Hill sand
		Rl	Red Hill sandy clay loam
		Rc	Red Hill complex
		TK	Te Kopuru sand
Omu	Claystone, shale etc.	OM	Omu clay loam
		AP	Aponga clay
		MA	Mata clay
		OA	Okaka silty clay and clay
		YK	Waikare clay
		H	Hukerenui silt loam
		WK	Wharekohe silt loam
Omanaia	Sandstone + mudstone	WN	Whirinaki clay loam
		ON	Omanaia clay loam
		AE	Autea clay loam
Puhoi	Banded sandstone	AN	Atuanui clay loam
		OI	Puhoi clay loam
		WR	Whangaripo clay loam
		WA	Warkworth clay
Waiotira	Massive sandstone	WC	White Cone sandy clay
		Y	Waiotira clay loam
		Yr	Waiotira brown clay loam
		Ye	Waiotira light clay
		RP	Riponui clay and sandy clay
		YKs	Waikare clay and sandy clay loam
		Hs	Hukerenui sandy loam
		WKs	Wharekohe sandy loam
Marua	Greywacke	TR	Te Ranga clay loam and stony clay loam
		MR	Marua clay loam
		RA	Rangiora clay, clay loam and silty clay loam
		Hr	Hukerenui silty loam, yellow subsoil phase
Maungarei	Dacite	PE	Parakiore stony clay loam
		PR	Parahaki silt loam and fine sandy loam
Huia	Andesitic breccias and conglomerates	HA	Huia stony clay
		YT	Waitakere clay
Te Kie	Doleritic breccias and tuffs	TE	Te Kie stony loam
		TU	Takitu clay loam
		A	Awapuku clay loam
		YN	Waimatenui clay
		AW	Awarua clay
		RU	Rangiuru clay
		TP	Tinopai sandy loam
Katui	Andesitic flows	KT	Katui clay loam

TABLE 6 (Continued)

Suite	Parent Material	Symbol	Soil Type
		WT	Whatoro clay
		TO	Tutamoe friable clay
		AR	Aranga clay
Kohumara	Alluvium from andesitic basalt	KM	Kohumara clay
		P	Pakotai clay
Haunga	Basalt and sandstone	HH	Hihi clay
Kaimaro	Andesitic basalt and claystone	OB	Onatai clay and loam
Parau	Andesitic tuff and sediments	DV	Dome Valley clay loam
		PA	Parau clay loam
Kiripaka	Basalt flows	OH	Ohaewai silt loam
		WI	Whatitiri clay loam
		MC	Matarau friable clay
		KE	Kerikeri clay loam
		RT	Ruatangata friable clay
		OK	Okaihau gravelly friable clay