Forestry and Protected Area Management
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LANDCARE RESEARCH
MANAAKI WHENUA

A reference manual for understanding and managing the soil resources of Niue

Food and Agriculture Organization of the United Nations

gef

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Foreword –Niue Soils Resource Manual

I have great honour in presenting the first *Reference Manual for Understanding and Managing the Soil Resources of Niue.* The Manual was developed for the purposes of understanding the physical and chemical properties of Niue's invaluable Soil Resources. More importantly it was developed as a reference guide for field-soil identification, soil fertility information, and soil attributes that are suitable for maximum crop growth, including the suitability of soil types for growing a wide range of important forestry and agricultural crops in Niue. The Manual will contribute to sustainable national Agriculture Production and Development.

The Manual was developed in alignment with the strategic direction set under the Niue National Strategic Plan, supporting key economic development initiatives through the sustainable utilization and management of natural resources, and contributing to the National Food and Nutritional Security of the Niue population. The Manual also support the Environment Pillar for Sustainable management of Niue's natural resources for future generations.

For many decades Niue soils have contributed significantly to supporting the lives of almost all Niuean people in relation to food security and income generating opportunities. Therefore it is of paramount importance that we all nurture and safeguard our environment from soil-loss, degradation, and from poor agricultural practices including adverse climate change impacts. We must ensure that we adhere to practicing sustainable agricultural farming methods and soil enhancement techniques in order to re-vitalise our soils for agriculture development of future generations.

The Manual paves a way forward in providing sound practical guidelines for all local farming communities for successful high yield crop production techniques through crop suitability ratings, as well as scientific information for future researchers. The Department of Agriculture, Forestry and Fisheries through the Ministry of Natural Resources will ensure that the Manual will be available and widely accessible by all relevant stakeholders for future use and reference.

I am sincerely grateful for the assistance given by FAO under the Forestry Protected Area Management Project, the Department of Agriculture, Forestry and Fisheries, Land Care Organisation-New Zealand, the Department of Environment, and Dave Leslie in particular for his expertise and scientific advice in compiling this first Reference Manual for Understanding and Managing the Soil Resources of Niue.

Fakaue Lahi mo e Fakamonuina mai he Atua.

Hon. Billy Graham Talagi
Minister
Ministry of Natural Resources

A reference manual for understanding and managing the soil resources of Niue

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1 Introduction

Publication of *A reference manual for understanding and managing the soil resources of Niue* is an initiative to collate and organise the current knowledge about Niue's soils and their management. As knowledge and understanding of soils grow, particularly of soil water management, soil fertility, crop options and sustainable farming systems, further revisions can be made.

The main purpose in compiling the manual is to provide agricultural extensionists and researchers, planners, farmers, and others working in the rural development sector with a ready guide to the field identification of soils, soil attributes important for optimal crop growth, information about soil fertility, and an evaluation of the suitability of the soils to grow a wide range of timber species, fruit and vegetable crops.

The text, tables and overall format of the Manual has been designed and written to be a user-friendly reference.

The re-interpreted information in the Manual has been derived from the very comprehensive technical report – *Soils and agriculture of Niue Island* (Wright & Van Westerndorp 1965) – and the revision of Wright and Van Westerndorp's soil map (Leslie 1986a) with modern laboratory soil characterisation and soil classification of soil series (Leslie 1986b).

The Manual has been structured to provide a logical flow of information as follows:

- physiographic soil legends, where soil series are hierarchically organised according to landscape type and the composition and depth of parent material
- factors of soil formation and the soil pattern for Niue
- classification of soil series according to Soil Taxonomy;
- key to identification of soil series; the flow-diagram format is also in a hierarchical order as for the physiographic soil legend
- chemical characteristics of soils
- soil fertility of selected soils
- Fertility Capability Soil Classification of soil series
- soil limitations
- land and soil attributes significant for crop growth
- matching of soil attributes with crop requirements, expressed in one of four classes of suitability. Based on this analysis, GIS-generated crop and timber species maps are available separately
- important references are provided in support of the foregoing and for further reading.

2 Physiographic Legend for Soil Series of Niue

In the following physiographic legend for the soil map of Niue the soil series have been arranged under physiographic headings with the initial subdivision separating soils of the marine-cut platforms, and the elevated plateau rim and rim margins from those of the central depressed plateau.

The second level separation groups soils into major landscape categories, for example, "soils of the karst landscape", "soils of the 'desert-plain' landscape", etc.

At the third category level soils are further differentiated on the basis of soil depth and the nature of the parent material from which they develop, for example, from "deep weathered clays over cemented calcareous reef rock".

The physiographic legend is that developed to accompany the *Soil Map of Niue*, scale 1:50 000 (Leslie 1986a). Symbols for each soil identified on the soil map are given.

2.1 Soil Legend for Niue Arranged Physiographically

SOILS OF THE MARINE-CUT PLATFORM ('ALOFI TERRACE')

- **Karst landscape**

From shallow weathered clays over cemented calcareous reef rock

HIKUTAVAKE SOILS Ht

From deep weathered clays over cemented calcareous reef rock

AVATELE SOILS Av

SOILS OF THE ELEVATED PLATEAU RIM AND THE RIM MARGINS ('MUTALAU REEF')

- **'Desert-plain' landscape**

From shallow weathered clays over lagoonal sediments (makatea)

TOI SOILS To

From very shallow weathered clays over lagoonal sediments (makatea)

VAIEA SOILS Va

From very shallow weathered clays over lagoonal sediments (makatea)

TUMUFA SOILS Tu

From moderately deep and deep weathered clays over lagoonal sediments (makatea) on cemented calcareous reef rock

FONUAKULA SOILS Fk

- **Karst landscape**

From shallow weathered clays over lagoonal sediments (makatea) on cemented calcareous reef rock

MUTALAU SOILS	Mu

From deep weathered clays over cemented calcareous reef rock

HAKUPU SOILS	Hp

From deep weathered clays over cemented calcareous reef rock

FOA SOILS	Fo

SOILS OF THE CENTRAL DEPRESSED PLATEAU (‘ANCIENT LAGOON’)

- **‘Desert-plain’ landscape**

From shallow weathered clays over lagoonal sediments (makatea)

NIUFELA SOILS	Ni

From shallow weathered clays over lagoonal sediments (makatea)

TAFOLOMAHINA SOILS	Ta

- **Karst landscape**

From shallow weathered clays over cemented calcareous reef rock

FETIKI SOILS	Ft

From deep weathered clays over cemented calcareous reef rock

PALAI SOILS	Pa

3 Objectives

3.1 Climate

Niue Island, an uplifted coral atoll, 21 km long and 17k m wide, has a total area of 260 km^2 and lies within the tropical zone at 19º 02' S and 169º 52' W.

Niue has a hot humid tropical climate with pronounced 'wet' (November to April) and 'dry' (May to October) seasons. Alofi, the only climate station with long-term records, has a mean annual rainfall of 2066 mm. Rainfall is unevenly distributed with the 4 months, June to September, receiving 408 mm or <20 percent of the annual total. During the 'dry' season soil moisture deficits occur and serious droughts are not uncommon. Dry months (i.e. months with less than 60 mm of rainfall) occur in every month of the year excepting March. June and July are normally the driest months in the year, but dry periods of 2–3 months are frequent, and up to 6 dry months in succession have been recorded. Moderately dry months (i.e. months with less than 100 mm of rainfall) are quite common, particularly from May to August, and owing to the high evaporation at this time soils become quite dry. Niue soils satisfy the criteria for an ustic moisture regime (Soil Survey Staff 2014).

Mean annual soil temperatures exceed 22ºC, and the difference between mean summer and mean winter soil temperatures is less than 5ºC, thus satisfying criteria for the isohyperthermic temperature regime (Soil Survey Staff 2014).

The average relative humidity of air at 9 am is 89%, with a minimum of 73% and a maximum of 95%. Although the relative humidity is fairly high, the SE trade winds blow steadily for most of the year. They are particularly reliable from April to October, and soils without plant cover suffer relatively intense evaporation.

3.2 Vegetation

Remnants of the original forest cover (2500 ha) are found mainly in central, eastern, and south-eastern parts of the central plateau. Locally kafika (*Eugenia inophylloides*) is the dominant tree. Other tree species include ovava (*Ficus prolixa*), puka (*Hernandia ovigera*), kuiti (*Pittosporum brackenridgei*), ifi (*Inocarpus fagiferus),* ai *(Canarium harveyi*), and koka (*Baccaurea tahitensis*).

Small remnants of a coastal type of forest occur on the eastern outer rim of the plateau, mainly occupying very rocky slopes leading down to the coastal shelf. The coastal forest has no truly dominant tree, but the following species are common: puka (*Hernandia ovigera*), tavahi kaku (*Leucaena* sp.), tuitui (*Aleurities moluccana*), fetau (*Calophyllum inophyllum*), and futu (*Barringtonia asiatica*).

The remainder of the island (22 500 ha) is covered with secondary forest growth, shrub, scrub or ground fern communities, and a much lesser area of subsistence crops. A land cover map of Niue (as at September 1994) is presented in Appendix 4.

3.3 Geology and landforms

Niue has a continuous rim called "makatea", and a flat, dry basin inside the rim that has been previously described (Schofield 1959) as an ancient lagoon. The island has no surface streams, because the coral is so porous, and rocks are dominated by calcite, aragonite, and dolomite minerals. There is no detailed geological map of the underlying rocks, but analyses (Blakemore et al. 1979) from the soil survey (Leslie 1986a) give the composition of the limestone underlying each soil map unit.

The interior of the island comprises a surface veneer with thicknesses up to 1.5 m. Over coralline materials, however, the average thickness is less than 30 cm. The soil mineralogy consists mainly of gibbsite, goethite, boehmite, and crandallite covering an irregular surface of highly weathered, pinnacle coral and dolomite, especially dolomite.

From known fossil material gathered in the ancient lagoon in the centre of the island, coral ceased to grow in the central area – 1.8 Ma. BP (Schofield 1959). Any submergence of the island since must have been relatively brief, and did not allow the growth of major amounts of further coral in the central area.

The Niue landscape shows four main landform categories: (i) the rim of the plateau representing an ancient reef half to one and a half kilometres in width; this encircles; (ii) a central depressed area representing an ancient lagoon with a maximum depth of 30 m and occupying an area of approximately 17 000 ha; outside the rim there is (iii) the seaward slope formed by the emergence of the ancient reef; and etched in this slope there is (iv) an incomplete encircling shelf, varying in width from 200 m to 400 m.

On the central plateau the inner margin of the Mutalau reef is marked by a zone of beach sands. These beds, which underlie the soil, are known as 'makatea'. The makatea deposits become distributed in an irregular manner towards the centre of the ancient lagoon. The Alofi terrace also has a layer of unconsolidated limestone fragments below the soil – a type of beach conglomerate representing debris produced by cliff erosion during the period of wave cutting that gave rise to the terrace.

The hard, basement main rock mass of Niue consists of coral reef rock; on this rests all the above transported materials. Hard coral limestone protrudes through the unconsolidated beds to such a degree that it forms the main surface rock of the island. Outcrops of hard reef rock occupy 48% of the surface of Niue.

Much of this land falls within the area mapped as Hikutavake soil series, a unit comprising 100 ha of soil interspersed among 1900 ha of rock.

3.4 Significance of soil composition and constitution

The nature of the original parent materials that gave rise to the soils of Niue has been the subject of scientific interest and inquiry for many years. The soils exist as a thin mantle resting on many different forms of coral limestone or their erosional derivatives.

The following points are significant:

(i) The soils are extremely low in silicon. Thus the 1:1 and 2:1 layer silicates, including kaolins and micaceous clays are absent. The soils are friable rather than cohesive, and apart from organic matter lack colloids capable of retaining potassium.

(ii) The soils are of a very advanced state of weathering. There is an absence of primary minerals with the exception of magnetite which is present in amounts up to 2% in some of the soils. It is assumed that the magnetite in these soils is of primary origin and a resistant residue from weathering of volcanic ash.

(iii) Reserves of total inorganic potassium are very low (0.1 to 0.7%). Exchangeable potassium of most soils (0–3 to 0.5 me.%) is also low and results in potassium deficiency particularly since exchangeable calcium and magnesium are always relatively high.

(iv) Total phosphorous on the island, probably derived from excreta of seabirds that congregated round the rim of the ancient lagoon, is uniformly high and most it is in the form of calcium aluminium phosphate (crandallite, $CaAl_3$ $[Po4]_2$ $[OH]_6$). The amounts of crandallite increase from the centre of the basin towards the rim of the plateau, meaning the soils of the rim may contain up to 40% crandallite.

(v) The phosphorous of crandallite, although of limited availability to plants, appears able to supply their requirements moderately well in Niue soils, particularly where crandallite contents are high; however, there have been indications of phosphorous deficiencies in some soils.

(vi) The other principal mineral constituents of the soils are secondary oxides of aluminium and iron, mainly gibbsite, goethite and haematite. These constituents make the soils friable, free-draining, and liable to dry out severely under prolonged drought conditions.

(vii) Many of the soils have high natural radioactivity which has significance in relation to their origin.

Fieldes *et al*. (1960) showed that most of the radioactivity in the Niuean plateau soils is due to radium –226, an intermediate daughter product of thorium –230, and both are daughter products of the naturally radioactive element uranium –238. Fieldes suggests that the radium –226 in the soils appears to have become separated from its parent, uranium –238, and that a separation of this type occurs during marine sedimentation where the uranium tends to stay in solution whereas its daughter products, thorium –230 and radium –226, are deposited by precipitation and absorption. The absence of equilibrium of this type in Niuean soils suggests the radioactive constituents have been derived from sea water. In waters remote from large land masses, where sediments accumulate very slowly, the radioactivity of the sediment may become relatively high if the production of radioactive material proceeds more rapidly than its dilution by the arrival of fresh sedimentary material. Using this conclusion, Fieldes hypothesises that the soils of Niue were originally derived mainly from reef sediments, accumulating very slowly in the central lagoon, subsequently mixed with volcanic ash.

4 The Soil Pattern of Niue

The field soil survey was conducted over two periods – a total of 10 weeks – during 1978 and 1979. The provision of field assistants by the Niue Government allowed selected soil pits to be dug in advance of soil description. Recorders were also provided to help with descriptions and provide `local` knowledge about previous and current land use and botanical identification. Sixty-five percent of field time was spent in describing soil pits and making auger observations, predominantly along pre-selected traverses. These traverses were selected recognising the Wright and Van Westerndorp soil pattern, geological information, and landscape units differentiated from aerial photos. The remaining time was spent mapping and sampling the representative profiles for laboratory analysis. Free survey methods were employed, with density of observation varying because access was denied for 'tapu' (sacred) areas, and, in some heavily forested areas, underfoot terrain difficulties (>80% rock outcrop). In all, 562 soil observations were made (147 soil pits, 415 auger observations).

The soils of Niue were first mapped, named, and classified by Wright and Van Westerndorp (1965). This soil survey showed a very complex and highly irregular soil pattern yet a simple broad grouping of soils into four series – Hikutavake, Hakupu, Fonuakula, Palai – which were clearly differentiated by the subsoil colours, which range from very dark grey, through brown and reddish brown, to dark red. Running parallel with this subsoil colour grouping, the topsoil textures determined in the field change from silt loam, through loam and silty clay loam to clay loam. Fifteen mapping units were identified in their survey.

Wright and Van Westerndorp recognised a range of profiles in each of the four series, depending partly on the depth of the soil over the limestone, partly on the amount of coral rock protruding the soil mantle, and partly on the degree to which ironstone concretions are developed in the soil. In this survey soil mapping units were selected that effectively delineated the main variants within the series. Thus, for example, the soil map shows Palai clay loam; Palai clay loam, variant with many limestone outcrops; Palai clay loam, variant with very many limestone outcrops; and Palai clay loam, variant with fine ironstone gravel – all subdivisions of the Palai series.

The soil series names established by Wright and Van Westerndorp have been retained, and the map unit boundaries correlate well between the two surveys; however, application of the Soil Taxonomy classification system necessitated creating nine new soil series, primarily because of the application of the pedon concept fundamental to Soil Taxonomy. Table 1 gives the correlation between Wright and Van Westerndorp (1965) and Leslie (1986a). Full profile and site descriptions are described in the Soil Taxonomic Unit Descriptions (Leslie 1986b) with abbreviated profile descriptions given in Table 2.

A series of single factor maps (5) are presented in Appendix 3: depth to cemented coral rock; surface stones and boulders; surface limestone rock outcrops; depth to makatea; and coarse fragments (coralline stones and/or boulders) in upper 50 cm.

Table 3 gives an analysis of area, spatial distribution and land use for each of the soil series.

Table 1 Correlation of Niue soils: Wright and Westerndorp (1965) with Leslie (1986a)

SOIL SERIES (Wright and Westerndorp, 1965	Map Symbol		SOIL SERIES (Leslie, 1986a)	Map Symbol
Hikutavake rocky silt loam	1	{	Hikutavake	Ht
Hikutavake hill soils	1H			
Hikutavake – Hakupu complex	1a		Avatele*	Av
Hakupu silt loam	2		Toi*	To
Hakupu silt loam – many limestone outcrops	2a		Mutalau*	Mu
Hakupu silt loam – very many limestone outcrops	2b		Hakupu	Hp
Fonuakula silty clay loam	3		Fonuakula	Fk
Fonuakula silty clay loam, shallow phase	3a		Vaiea*	Va
Fonuakula silty clay loam, many limestone out crops	3b	{	Foa*	Fo
Fonuakula silty clay loam, very many limestone outcrops	3c			
Fonuakula silty clay loam with fine ironstone nodules	3d		Tumufa*	Tu
Palai clay loam	4		Niufela*	Ni
Palai clay loam – many limestone outcrops	4a		Fetiki*	Ft
Palai clay loam – very many limestone outcrops	4b		Palai	Pa
Palai clay loam with fine ironstone nodules	4c		Tafolomahina*	Ta

* new soil series

Table 2 Niue abbreviated profile descriptions

Horizon	Depth (cm)	Matrix Colour (moist)	Concretions			Texture	Consistence	Structure	Coarse materials		Other	Boundary
			Abundance	Size	Colour				Boulders	Stones		
Avatele series												
Ah	0–10	7.5YR 3/2	-	-	-	stony silty clay loam	loose	medium nut	-	50% coralline	-	indistinct
Bw1	10–55	5YR 4/6	-	-	-	silty clay loam	very friable	weak v.f. nut	20% coralline		-	diffuse
Bw2	55–120	5YR 4/6	-	-	-	silty clay loam	friable	single grain	-	10% coralline	-	sharp (lithic contact)
2R	*on* cemented coral limestone											
Fetiki series												
A	0–20	5YR 3/2	-	-	-	clay loam	friable	str. med. nut	-	-		diffuse
Bw1	20–33	2.5YR 3/2	-	-	-	clay loam	friable	str. med. blocky	-	-	-	indistinct
BW2	33–58	2.5YR 3/6	-	-	-	clay loam	very friable	mod. fine granular	-	-	-	sharp (lithic contact)
2R	*on* cemented coral limestone											
Foa Series												
A	0–18	5YR 3/2	5%	fine	2.5YR 4/6	silty clay loam	friable	str. fine nut	-	-	-	distinct
Bw1	18–33	2.5YR 3/4	5%	fine	2.5YR 4/6	clay loam	friable	str. fine nut	-	-	-	diffuse
Bw2	33–98	2.5YR 3/6	5%	fine	2.5YR 4/6	clay loam	friable	mod. fine crumb	-	-	-	sharp (lithic contact)
2R	*on* cemented coral limestone (5Y 8/1)											
Fonuakula series												
Au1	0–20	5YR 3/3	10%	fine	2.5YR 4/6	silty clay loam	very friable	mod. fine nut	-	-	-	Distinct
Au2	20–36	5YR 3/4	10%	fine	2.5YR 4/6	silty clay loam	very friable	str. fine nut	-	-	-	Indistinct
Bw1	36–56	5YR 4/6	5%	fine	2.5YR 4/6	clay loam	friable	weak fine crumb	-	-	-	Distinct
Bw2	56–125	5YR 4/6	-	-	-	silty clay	friable	weak fine crumb	-	-	-	Sharp
2C	125–200	5Y 8/1	-	-	-	coarse sand	very firm	single grain	-	-	makatea	

Horizon	Depth (cm)	Matrix Colour (moist)	Concretions Abundance	Concretions Size	Concretions Colour	Texture	Consistence	Structure	Coarse materials Boulders	Coarse materials Stones	Other	Boundary
Hakupu series												
Ah1	0–12	5YR 3/2	-	-	-	silt loam	very friable	str. medium nut		5% coralline	-	Indistinct
Ah2	12–28	7.5YR 3/2	-	-	-	silt loam	very friable	mod. fine nut	10% coralline	-	-	Indistinct
Bw1	28–42	5YR 3/4	5%	fine	10YR 3/6	silt loam	very friable	weak medium nut	10% coralline	-	-	Distinct
BW2	42–70	5YR 4/6	-	-	-	silty clay loam	very friable	weak co. blocky	10% coralline	-	-	sharp (lithic contact)
2R	*on* cemented coral limestone (5Y 8/1)											
Hikutavake series												
Ah	0–19	7.5YR 3/2	5%	fine	5YR 3/4	silt loam	friable	str. med. nut	-	20% coralline	-	Indistinct
AB	19–32	5YR 3/4	5%	fine	5YR 3/4	silt loam	friable	mod. fine nut	-	10% coralline	-	indistinct
Bw	32–48	5YR 4/8	5%	fine	2.5YR 3/6	silty clay loam	friable	mod. fine crumb	-	5% coralline	-	sharp (lithic contact)
2R	on cemented coral limestone (5Y 8/1)											
Mutalau series												
Au1	0–11	5YR 3/2	10%	fine	5YR 4/8	silt loam	very friable	str. fine nut	-	-	-	indistinct
Au2	11–30	5YR 3/3	5%	fine	5YR 4/8	silty clay loam	very friable	str. fine nut	-	-	-	indistinct
Bw	30–56	5YR 4/4	-	-	-	clay loam	friable	weak co. blocky	-	-	-	sharp
2C	56–100+	5Y 8/1	-	-	-	stony coarse sand	loose	single grain	-	-	makatea	-

Horizon	Depth (cm)	Matrix Colour (moist)	Concretions			Texture	Consistence	Structure	Coarse materials		Other	Boundary
			Abundance	Size	Colour				Boulders	Stones		
Niufela series												
Au1	0–10	7.5YR 3/2	5%	fine	2.5YR 4/6	clay loam	friable	str. fine nut	-	-		indistinct
Au2	10–26	5YR 3/3	10%	fine	10YR 3/6	clay loam	friable	str. fine nut	-	-		indistinct
Bw	26–42	2.5YR 3/4	-	-	-	clay loam	friable	weak med. blocky	10% coralline	-		sharp
2C	42–100+	5Y 8/1	-	-	-	stony v. co. sandy loam	loose	single grain		60% coralline	makatea	-
Palai series												
Au1	0–20	5YR 3/3	15%	fine	5YR 3/4	clay loam	friable	str. fine nut	-	-	-	indistinct
Au2	20–35	5YR 3/4	15%	fine	5YR 3/4	clay loam	friable	str. fine nut	-	-	-	indistinct
Bw1	35–42	2.5YR 3/6	10%	fine	5YR 3/4	clay loam	friable	mod. fine crumb	-	-	-	indistinct
Bw2	42–120	2.5YR 3/4	-	-	-	clay loam	friable	weak med. blocky	-	-	-	Sharp
2R	*on* cemented coral limestone (5Y 8/1)											
Tafolomahina series												
	0–1	-	100%	med.	5YR 3/4	-	loose	-	-	10% coralline	-	distinct
A	1–15	5YR 3/3	15%	fine	5YR 3/4	silty clay loam	friable	str. fine nut	-	10% coralline		indistinct
Bw	15–46	5YR 3/3	5%	fine	5YR 3/4	clay loam	friable	str. fine nut	-	15% coralline	-	sharp
2C	46–152	5Y 8/1	-	-	-	v. co. sandy loam	loose	-	-	shelly	makatea	sharp (lithic contact)
2R	*on* cemented coral limestone (5Y 8/1)											

Horizon	Depth (cm)	Matrix Colour (moist)	Concretions Abundance	Concretions Size	Concretions Colour	Texture	Consistence	Structure	Coarse materials Boulders	Coarse materials Stones	Other	Boundary
Toi series												
Au1	0–15	7.5YR 3/2	5%	fine	2.5YR 3/4	silty clay loam	very friable	str. medium nut	-	-	-	indistinct
Au2	15–30	7.5YR 3/2	5%	fine	2.5YR 3/4	silty clay loam	very friable	str. fine nut	-	-	-	indistinct
Bw	30–45	5YR 4/4	10%	fine	5YR 4/8	silty clay loam	friable	mod. fine crumb	-	-	-	sharp
2C	45–100+	5Y 8/1	-	-	-	stony coarse sand	firm	-	-	-	makatea	
Tumufa series												
	0–1	-	100%	fine	5YR 4/6	-	-	-	-	-	-	distinct
Au1	1–10	5YR 3/2	25%	fine	5YR 4/6	silty clay loam	friable	str. fine crumb	-	15% coralline	-	indistinct
Au2	10–22	5YR 3/4	5%	fine	5YR 4/6	silty clay loam	friable	str. fine nut	-	15% coralline	-	distinct
2C	22–120	5YR 7/3	-	-	-	coarse sand	loose	massive	40% coralline	30% coralline	makatea	
Vaiea series												
Au1	0–10	7.5YR 3/2	7%	fine	2.5YR 3/4	silt loam	friable	str. fine nut	-	20% coralline	-	indistinct
Au2	10–20	7.5YR 3/2	5%	fine	2.5YR 3/4	silt loam	friable	str. fine nut	-	20% coralline	-	distinct
2C	20–120	5Y 7/3	-	-	-	coarse sand	Loose	-	40% coralline	20% coralline	makatea	

Table 3 Soil series spatial distribution, and land use

Soil series	Area of soil series (ha)	Distribution	Land use
Avatele	453	Confined to long and narrow units on the Alofi terrace near Liku village east coast, and along the north and west coasts of the island.	Utilised for the full range of subsistence, vegetables, root crops and tree crops. In the natural state supports regenerating forest species and forest ferns.
Fetiki	2808	Extensive with the karst landscape of the 'ancient lagoon' in the central part of the island.	Used extensively for yam, kumara and taro, and subsistence banana cropping. In natural state supports tall forest, dominated by Kafika and Kolivao and luxuriant understory of ferns and regenerating tree species.
Foa	4552	Forms an extensive concentric distribution on the karst landscape of the 'Mutalau reef' which encloses the central 'ancient lagoon' of the island.	Mainly used for taro and kumara crops, with a bush fallow interval of 8–15 years. Were widely used for coconut, banana and breadfruit. Only few remnants of the original forest cover now remain. In the unused state covered with fern, and open, low, second-growth forest.
Fonuakula	2703	Although most extensive in the SE sector of the island, patchy distribution pattern of the 'desert plain' landscape of the 'Mutalau reef' which encloses the central 'ancient lagoon' of the island.	Mainly used for root crops, but with a bush fallow interval of 8–15 years. Were widely used in the past for banana, coconut and breadfruit. Only few remnants of original forest cover now remain. In the unused state covered with fern, and open, low, second-growth forest.
Hakupu	1820	Forms a narrow and continuous encircling unit within the karst landscape and the outer rim margins of the 'Mutalau reef'.	Mainly used for taro and coconuts. Original cover was forest and in the more exposed locations coastal scrub, where remnants remain. Blue algae cover rock outcrops.
Hikutavake	2091	Forms a narrow and continuous concentric unit at the outer margins of the island, where it extends from sea level up onto the karst landscape of the 'Alofi terrace'.	Forest and scrub remnants are extensive. Despite excessive rockiness, is one of the more productive soils on the island. Breadfruit and mango trees grow well in the eastern coastal districts; bananas and root crops thrive wherever pockets of deeper soils can be found.
Mutalau	3125	Most extensive to the north of the island in association with Toi series. Forms a near continuous encircling unit within the karst landscape on the elevated plateau rim of the 'Mutalau reef'.	Original forest, in which kafika is dominant, is extensive. Coconut and most varieties of taro grow fairly well.

Niufela	1436	Has a patchy distribution pattern that is related to the occurrence of the ‘desert plain’ landscape (fernlands) of the central ‘ancient lagoon’.	The soil grows very good coconuts and yams, and fairly good crops of banana and kumara. Some areas support the original forest cover in which kafika is dominant. Elsewhere, fern species and secondary scrub are predominant.
Palai	3379	Extensive throughout the central depressed plateau of the island, where its distribution pattern is related to the occurrence of the karst landscape, across this ‘ancient lagoon’ surface.	In the past one of the main commercial banana growing soils. Taro also grows well. While many areas of the soil support secondary scrub and regenerating forest species, most of the area is under the original forest cover (the Huvalu tapu forest is mainly Palai series) in which kafika dominates with kolivao.
Tafalomahina	260	Similar to Niufela series – it has a patchy distribution pattern related to the occurrence of the ‘desert plain’ landscape (fernlands) of the central ‘ancient lagoon’. More extensive at the northern margin of central depressed plateau.	History of having been heavily cropped in the past and commonly found near the sites of ancient inland villages. The soil was reputed to have grown good taro crops. An excellent soil for kumara and yam. Where unused supports fern species and scrub species. A feature of bared soil surfaces are the algal crusts of gelatinous Nostoc colonies (which fix atmospheric nitrogen).
Toi	2150	Forms long narrow units within the ‘desert plain’ landscape (fernlands) on the elevated plateau rim margins of the ‘Mutalau reef’ at the south and east of the island. Most extensive to the north of the island in association with Mutalau series.	Is almost always extensively planted in coconuts which grow very well. Grows moderately good taro and banana crops. Remnants of the forest that originally grew on these soils can be seen now only in Huvalu forest.
Tumufa	994	Occurs as four broad areas in the SE sector of the island where its distribution pattern is related to the occurrence of the ‘desert plain’ landscape (fernlands) of the elevated plateau rim and rim margins of the ‘Mutalau reef’.	Soils are of limited value for agriculture in their natural state. Cassava is the only crop that consistently produces a fair yield on these soils. For many years this soil has been burned annually to harvest wild arrowroot tubers. Commonly support fern and scrub and in areas of bared ground gelatinous Nostoc colonies predominate.
Vaiea	402	Series is not extensive and occurs in four areas in the southern part of the island where its distribution pattern is related to the occurrence of the ‘desert plain’ landscape (fernlands) of the elevated plateau rim and rim margins of the ‘Mutalau reef’.	The present vegetation in nearly every case is scrub or fern but formerly this soil may have supported light forest. Coconut trees grow slowly, few root crops are grown, and even cassava crops give only fair to poor yields.

5 Classification of the Soil Series According to Soil Taxonomy

5.1 Introduction

This section presents the soil classification of Niue soils according to Soil Taxonomy (Soil Survey Staff 2014) which allows correlation of soils of tropical countries with the soil series of Niue.

Before examining the classification it is important to understand the five following main reasons for soil classification:

1. To **organise** knowledge about soils. Organising our knowledge of soils helps us to think more clearly and efficiently about them.

2. To **understand** relationships between soils, and between soils and the environment in which they have formed. By understanding these relationships it can be seen why certain soils are similar and why others are different.

3. To **remember** the main properties of the soils being classified.

4. To **learn** new relationships between soils within the same class and between soils in different classes.

5. To **use** classification to make interpretations for land use. Soil classification helps establish groups of soils that can be used for practical applied purposes in:

    a. predicting soil behaviour

    b. estimating soil productivity and likely response to management

    c. providing a basis for extending or extrapolating results of research or accumulated land use experience. Results of agricultural research conducted on one site should be generally applicable to other sites that have the same soil.

Soil Taxonomy focuses on describing soils as they actually appear at present without undue emphasis on soil genesis. The classification is multi-categoric with few classes in the highest categories and large numbers in the lowest categories. Classes are precisely defined, based on analyses of real soils and measurable properties. The hierarchal structure of Soil Taxonomy is described below.

The initial category – *Order* – is determined by surface or subsurface diagnostic horizons or features. *Suborders* consider properties affecting current processes, e.g. moisture and temperature. Suborders are then subdivided into *Great Groups* that reflect the dominant properties of the soil. *Subgroups* define the less important properties to show relationships to other soils — typic, intergrade, extragrade. The *family name* identifies all the higher categories of the family, namely, subgroup, great group, suborder and order. For example, the Fonuakula series is in the *very fine, gibbsitic, isohyperthermic* family of *Oxic Haplustolls* (Fig. 1).

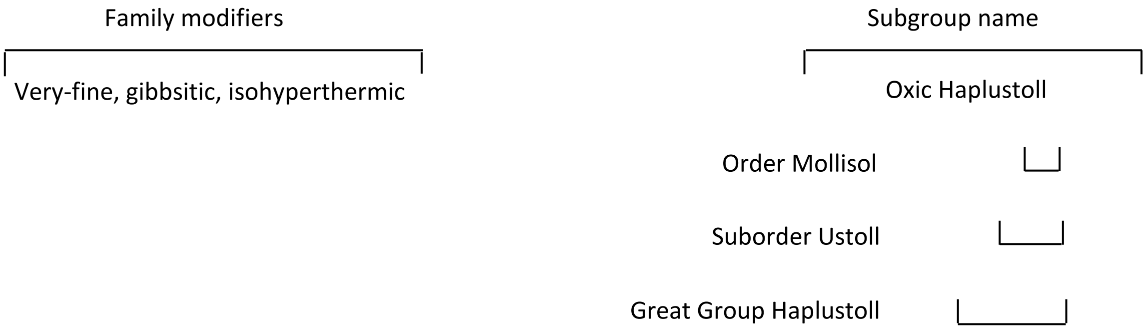


Figure 1 Construction of a complete family name.

The name gives us the following information about the Fonuakula soil series:

- It has a *mollic epipedon*, i.e. a thick, dark coloured, humus-rich (organic carbon >0.6%) with high base status (>50%) and classifies as a *Mollisol.*
- It is well drained and dry for 3 months during the growing season, i.e. an ustic soil moisture regime, and classifies as an *Ustoll*.
- It has a cambic subsurface horizon, i.e. having minimal soil development below the Mollic epipedon and classifies as a *Haplustoll.*
- It has a *very-fine* particle size class having 60% or more clay.
- It has a *gibbsitic* mineralogy class having more than 40% gibbsite and boehmite in the fine-earth fraction.
- It has a mean annual soil temperature >22°C (*hyperthermic*) and the annual range is <5°C (*iso*) so soil temperature regime is *isohyperthermic*.

Soil Taxonomy is Niue's national soil classification system, which provides a mechanism through which experiences from other tropical countries with 'like' soils could be applied to help the rural economy and to use new agro-production technologies from similar farming systems to develop Niue's land resources for increased food production and better nutrition. The mechanism also bypasses three key constraints faced by Niue's lack of trained personnel, lack of investment capital for the rural sector and, above all, lack of time to catch up with the country's needs. Farmers do not have the luxury of waiting decades for the results of slowly developing in-country agricultural technology.

The USAID-funded Benchmark Soils Project (BSP), developed and managed by the University of Hawaii, demonstrated that agro-production technology can be transferred from one tropical region to another on the basis of Soil Taxonomy at the soil family level of the classification.

The implication for food production is significant. First, millions of dollars' worth of research information will be available for immediate tapping. Second, costs of site-specific global trials will be saved, and the waste of human and other resources will be alleviated. Third, the BSP has developed a worldwide network of expertise and a Soil Data Bank to expedite and provide the needed information and communication for rural development. Last, agro-technology transfer is all-encompassing; it includes transfer of information on soil management practices and all that goes with it — information on crops and cropping systems, water management practices, erosion control measures, suitability for new crops, economics of crop production, use and problems of irrigation, and so on. The strengths of Soil Taxonomy are: use of quantitative criteria; concepts of diagnostic horizons; emphasis on criteria not readily altered by man; and its logical system of nomenclature.

Table 4 Soil Taxonomy classification for soil series of Niue Island

SOIL SERIES	FAMILY DIFFERENTIAE
Toi	Udic Haplustoll, very fine, crandallitic
Niufela	Udic Haplustoll, very fine, parasequic
Vaiea	Udorthentic Haplustoll, very fine, parasequic
Tumufa	Udorthentic Haplustoll, very fine, gibbsitic
Hikutavake	Ruptic-lithic Haplustoll, clayey, parasequic
Fonuakula	Oxic Haplustoll, very fine, gibbsitic
Fetiki	Ruptic-lithic Haplustoll, very fine, parasequic
Palai	Ruptic-lithic Haplustoll, very fine, parasequic
Hakupu	Ruptic-lithic Haplustoll, fine, crandallitic
Mutalau	Ruptic-lithic Haplustoll, very fine, parasequic
Foa	Ruptic-lithic Haplustoll, very fine, gibbsitic
Avatele	Udic Haplustept, fine, parasequic
Tafolomahina	Ruptic-lithic Haplustoll, very fine, gibbsitic

6 Flow-Diagram Keys for the Identification of Soil Series

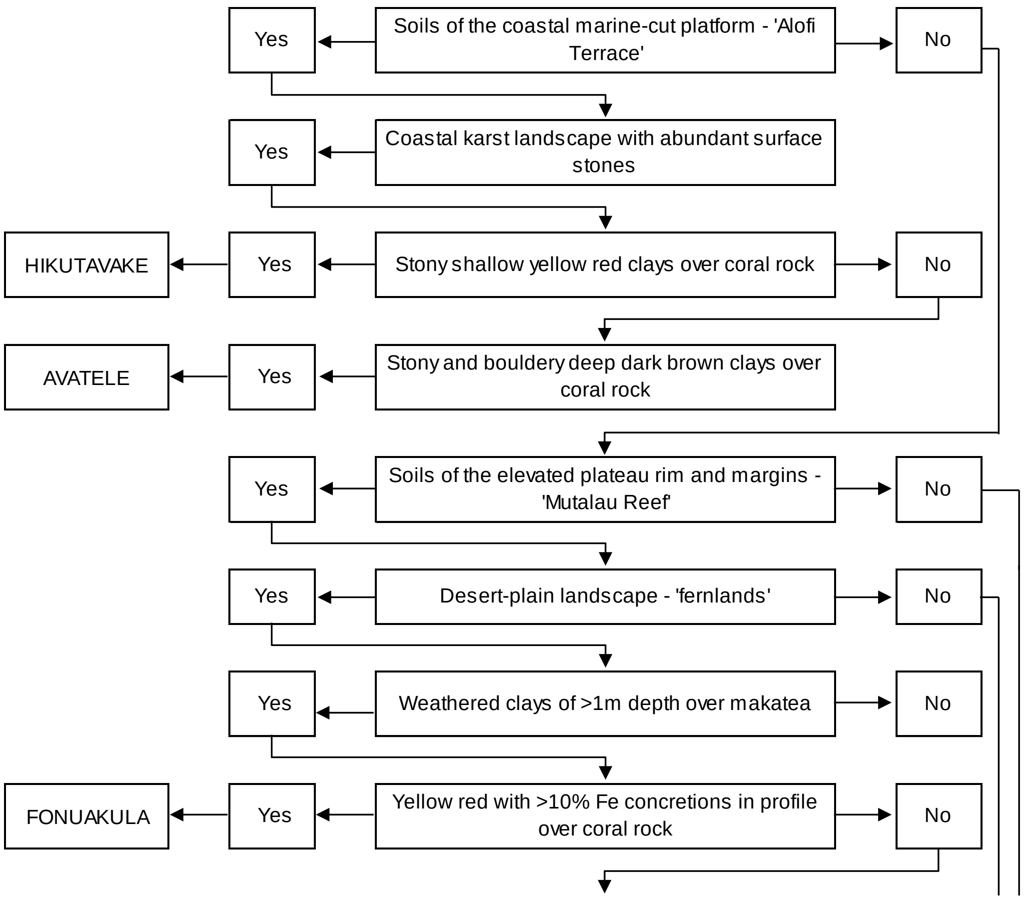
This section explains, in a flow-diagram format, keys to identify Niue soils in the field. The keys are intended to allow for easier identification of the soils and are likely to be particularly useful to persons not familiar with the structure of the soil taxonomic unit descriptions (Leslie 1986).

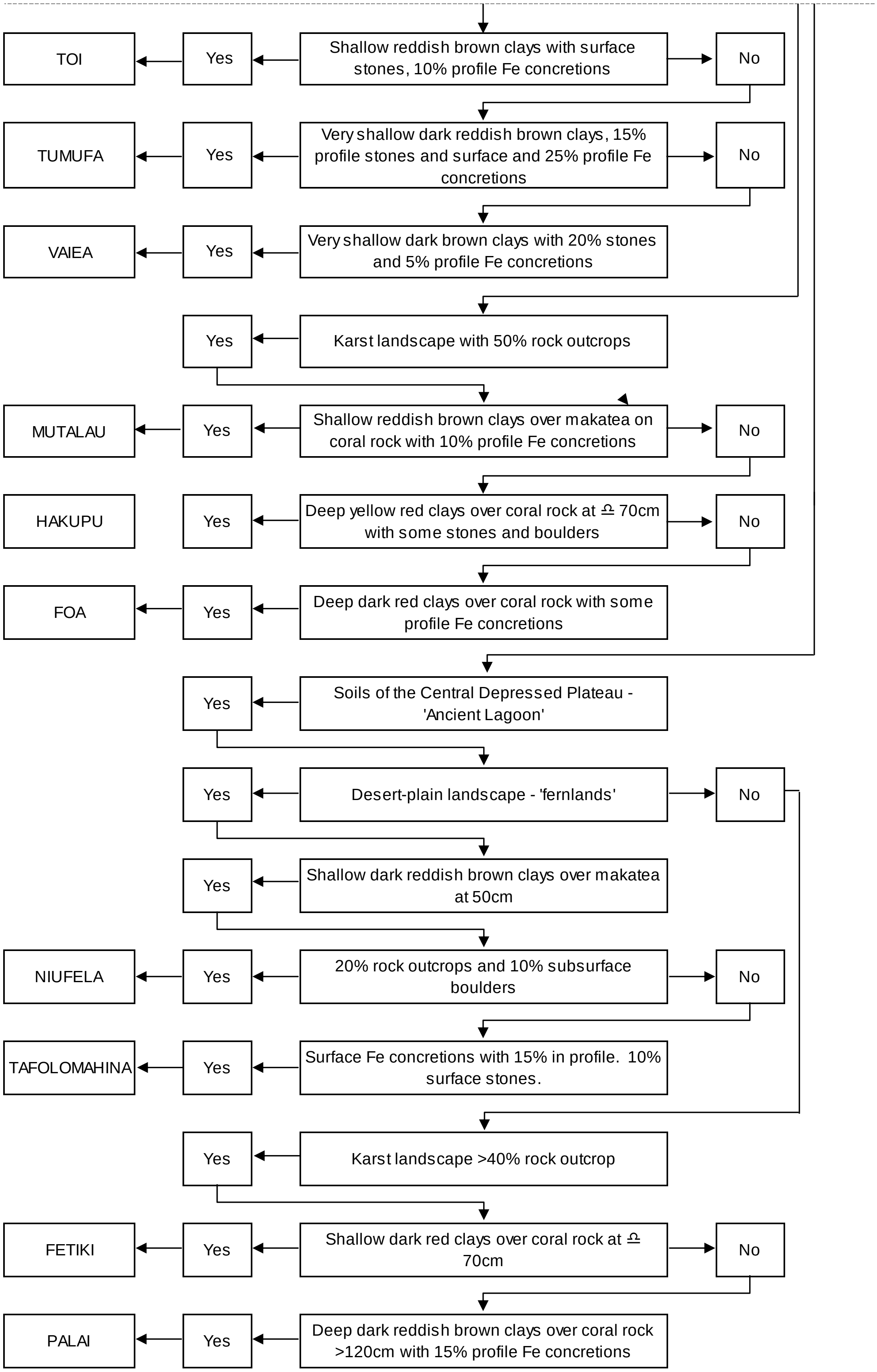
The key first separates soils into major landscape types, e.g. soils of the elevated plateau rim and margins, soils of the coastal marine-cut platform, etc. Further identifiers applied to help arrive at the soil series include: topography (e.g. desert-plain landscape – 'fernlands'); parent material (e.g. weathered clays of >1 m depth over makatea); and finally, to those soil profile properties that define the soil (e.g. shallow reddish brown clays with the surface stones, 10% profile Fe concretions).

An example for Niufela soils:

	Soils of the Central Depressed Plateau – 'Ancient Lagoon'	Yes
	Desert-plain landscape – 'fernlands'	Yes
	Shallow dark reddish brown clays over makatea at 50cm	Yes
No	20% rock outcrops and 10% subsurface boulders	Yes – Niufela series
→	Surface Fe concretions with 15% in profile. 10% surface stones	Yes – Tafolomahina series

Table 5 Keys to the identification of soil map units of Niue




TOI
Yes
Shallow reddish brown clays with surface stones, 10% profile Fe concretions
No
TUMUFA
Yes
Very shallow dark reddish brown clays, 15% profile stones and surface and 25% profile Fe concretions
No
VAIEA
Yes
Very shallow dark brown clays with 20% stones and 5% profile Fe concretions
Yes
Karst landscape with 50% rock outcrops
MUTALAU
Yes
Shallow reddish brown clays over makatea on coral rock with 10% profile Fe concretions
No
HAKUPU
Yes
Deep yellow red clays over coral rock at ♎ 70cm with some stones and boulders
No
FOA
Yes
Deep dark red clays over coral rock with some profile Fe concretions
Yes
Soils of the Central Depressed Plateau - 'Ancient Lagoon'
Yes
Desert-plain landscape - 'fernlands'
No
Yes
Shallow dark reddish brown clays over makatea at 50cm
NIUFELA
Yes
20% rock outcrops and 10% subsurface boulders
No
TAFOLOMAHINA
Yes
Surface Fe concretions with 15% in profile. 10% surface stones.
Yes
Karst landscape >40% rock outcrop
FETIKI
Yes
Shallow dark red clays over coral rock at ♎ 70cm
No
PALAI
Yes
Deep dark reddish brown clays over coral rock >120cm with 15% profile Fe concretions

7 Chemical and Physical Characteristics of Soils

Chemical analyses were carried out at the Soil Bureau, DSIR Laboratories at Taita according to standard Soil Bureau methods (Blakemore et al. 1972). The soil chemical analyses are presented in Table 6.

7.1 Chemical properties

The exact meaning of the chemical properties can be difficult to understand but even if the chemistry is not fully understood, some information can be taken from Table 6. For example, for Hikutavake, loamy clay (SB 9480 A-C), in Table 6 under Cation Exchange, figures for K (potassium) of 0.48, 0.04, and 0.02 are given for the 0–19 cm, 19–32 cm and 32–48 cm horizons respectively. Looking at the table of ratings (Appendix 3), under K we see that figures of more than 1.2 are very high, 0.8 to 1.2 are high, 0.5 to 0.8 are medium, 0.30 to 0.5 are low, and less than 0.3 are very low. Therefore the potassium or potash levels in these samples are low in the topsoil and very low in the lower horizons. Note that the ratings do not show deficiency levels for plant growth as these vary considerably from crop to crop.

In a similar way, Table 6 shows that the values of more than 40 for phosphorus (0.5 m $H_2SO_{4)}$ are very high. Therefore the phosphorus figures of 1183, 941, and 783 for Hikutavake loamy clay are very high.

In this way ratings for elements of particular interest such as K (potassium), P (phosphorus) or S (sulphur), or for organic matter (C, carbon) can be worked out. Ratings for Zn (zinc) figures are not given in Appendix 1 but the critical level, below which effects on growth are likely, is given as 1.4 ppm.

On studying the figures in Table 6 some general properties of Niuean soils can be seen, which confirm the conclusions made by Wright and van Westerndorp (1965). The soils of Niue are very similar in their chemical properties: the pH levels are not far from neutral; no strongly acid or strongly alkaline soils are found; and levels of Ca (calcium or lime) and Mg (magnesium) are usually high or very high, although subsoil levels may be lower.

K (potassium levels are generally low or very low. The amounts of Kc, or reserves of K that can in future become available from weathering, is negligible. K reserves in the soil may comprise both inorganic and organic forms. The inorganic or mineral K reserve is very low in both topsoils and subsoils ranging from 0.01 to 0.02 me. %, and is also fairly low in the underlying limestone. The organic reserve is held mainly in the plant tissues, and enters the soil system through the decay of leaves and twigs on the soil surface, where the soil organic K reserve is held mainly in the soil humus. Niue soils are K deficient, the more so since mineral reserves are virtually non-existent; and exchangeable Ca and Mg are invariably high so that the K/(Ca + Mg) ratios are always very low. A single factor map showing the distribution of potassium in soils is given in Appendix 4.

The CEC (cation exchange capacity), which measures the ability of soils to hold calcium, magnesium, potassium, and sodium in the soil and to prevent its removal by leaching by rain water, is very low in the soil minerals but very high in organic matter. As the soils are well supplied with organic matter CEC levels are generally satisfactory.

Carbon (C) or organic matter figures are high in the topsoils, and relatively high in the subsoils. The samples were taken from sites in forests or fernlands that have not been cultivated for a long time so would tend to be high. After burning or cultivation levels would be lower. While the figures for N (nitrogen) are also high, it should be noted these are total N figures and are not a measure of available nitrogen for crops.

Phosphorus (P) figures are very high in all the samples analysed. Phosphorus retention (P retn) figures are very high and might suggest some limitations on P availability, but the retention at neutral pHs will largely be by calcium and the P so held appears to be available in adequate quantities to crops. Most phosphate is in the form of the mineral crandallite. The amount of crandallite in the soil decreases and the amount of gibbsite increases in passing from the plateau rim towards the centre of ancient lagoon. In the centre of the lagoon, crandallite cannot be detected in X-ray patterns. Crandallite forms under conditions of near neutral pH and abundant calcium in the soil, and the surprisingly high amount of available P in these soils appears to be correlated with the quantity of total P in the form of crandallite in the soils. The original source of the P present could be largely of organic origin (e.g. sea birds which would be expected to congregate around the rim of the ancient lagoon).

Sulphur (S), as shown by adsorbed sulphate (Ads S), is often low, but additions of S from the sea are constantly renewed so sulphur fertilisers may not be necessary.

Zinc (Zn) is low and often below the critical level of 1.4 ppm. See Appendix 4 for a single factor map showing topsoil zinc values in Niue soils.

Levels of CEC, K and Zn are closely linked to organic matter. The maintenance of organic matter levels by good management is therefore particularly important.

Table 6 Soil Chemistry

Soil & Depth (cm)	pH	Organic Matter C%	N%	Cation exchange (me. %) CEC	Σ Bases	BS%	Ca	Mg	K	Na	Reserve Kc (me. %)	Ads S (ppm)	Phosphorus Retn (%)	0.5m H_2SO_4	$CaCO_3$ (%)	Tamm Oxalate Al (%)	Fe (%)	Si (%)	Na (%)	Extr Zn (ppm)
Avatele stony loamy clay SB 9471 A-C																				
0-10	7.4	20.0	1.43	79.5	-- free lime --		10.70	0.89		0.61	0.01	40	91	241	4.0	2.2	0.71	0.01	0.30	3.1
10-55	7.6	5.1	0.43	22.1	26.2	(100)	23.9	2.07	0.08	0.12	0.01	12	99	338	0.6	2.5	0.89	0.01	0.23	0.6
55-120	7.7	4.7	0.37	22.4	25.7	(100)	23.8	1.71	0.10	0.13		15	99	446	0.9	2.5	0.80	0.01	0.23	0.5
Fetiki clay not sampled																				
Foa clay SB 9477 A-C																				
0-18	6.9	8.6	0.67	43.6	44.7	(100)	34.9	9.1	0.33	0.38	0.01	62	84	270	<0.1	0.95	0.36	0.01	0.16	1.0
18-33	6.9	2.6	0.18	12.6	12.7	(100)	9.5	3.1	0.03	0.06		18	89	239	<0.1	0.48	0.26	0.01	0.05	0.3
33-98	7.7	1.9	0.09	5.0	-- free lime --		7.0	0.01		0.05	0.01	18	94	135	0.5	0.27	0.14	0.01	0.02	0.2
Fonuakula clay loam SB 9474 A-D																				
0-20	7.6	7.3	0.41	28.8	-- free lime --		6.70	0.27		0.51	0.01	16	81	302	15.0	0.73	0.31	0.01	0.19	1.3
20-36	6.9	5.0	0.27	18.1	17.7	98	11.7	5.60	0.11	0.26		11	88	308	0.1	0.73	0.25	0.03	0.24	0.3
36-56	6.6	2.1	0.08	6.2	4.3	69	3.6	0.58	0.01	0.07	0.01	56	92	224	0.0	0.48	0.29	0.03	0.22	0.2
56-125	6.5	1.1	0.04	2.2	1.7	77	1.5	0.12	0.01	0.03		236	95	135	0.0	0.25	0.19	0.01	0.05	0.2
Hakupu loamy clay SB 9482 A-D																				
0-12	7.3	21.0	1.24	104.0	-- free lime --		24.1	1.00		1.42	0.01	33	84	671	2.0	2.00	0.88	0.04	0.12	2.2
12-28	7.5	11.0	0.84	59.9	70.4	(100)	59.4	9.8	0.41	0.79		30	94	699	0.4	2.90	1.42	0.04	0.13	0.9
28-42	7.8	4.7	0.31	25.6	37.1	(100)	30.7	5.9	0.10	0.41	0.02	17	97	856	0.3	2.40	0.81	0.07	0.09	0.4
42-70	7.9	2.5	0.14	16.6	19.7	(100)	14.3	5.1	0.04	0.27		20	97	950	0.3	1.19	0.32	0.06	0.02	0.3

Soil & Depth (cm)	pH	Organic Matter C%	N%	Cation exchange (me. %) CEC	∑ Bases	BS%	Ca	Mg	K	Na	Reserve Kc (me. %)	Ads S (ppm)	Phosphorus Retn (%)	0.5m H_2SO_4	$CaCO_3$ (%)	Tamm Oxalate Al (%)	Fe (%)	Si (%)	Na (%)	Extr Zn (ppm)
Hikutavake loamy clay SB 9480 A-C																				
0-19	7.4	13.9	0.85	68.9	-- free lime --		10.6	0.48		0.30	0.01	16	92	1183	1.0	3.1	1.14	0.05	0.18	4.8
19-32	7.6	5.8	0.39	29.4	27.3	93	21.9	5.2	0.04	0.16		18	98	941	0.4	3.0	0.83	0.07	0.23	1.0
32-48	7.7	3.9	0.25	25.5	20.7	81	16.7	3.8	0.02	0.21	0.02	36	99	783	0.5	2.7	0.52	0.09	0.13	0.7
Mutalau loamy clay SB 9472 A-C																				
0-11	7.5	7.9	0.50	39.6	53.2	(100)	44.0	8.80	0.28	0.14	0.01	13	77	465	0.06	1.06	0.51	0.01	0.27	1.3
11-30	7.1	5.6	0.43	26.7	28.8	(100)	23.6	4.90	0.19	0.11		6	88	398	0.01	1.08	0.40	0.02	0.30	0.5
30-56	7.2	2.2	0.14	8.8	12.8	(100)	10.9	1.79	0.05	0.09	0.01	4	92	340	0.01	0.55	0.27	0.01	0.20	0.3
Niufela loamy clay SB 9481 A-C																				
0-10	7.4	10.5	0.63	66.5	64.0	96	48.7	14.80	0.34	0.19	0.01	12	81	816	0.7	1.89	0.85	0.02	0.34	4.2
10-26	6.9	7.0	0.41	42.9	37.1	86	32.1	4.70	0.16	0.11		8	89	812	<0.1	1.89	0.76	0.01	0.38	1.2
26-42	6.8	2.2	0.13	16.2	13.9	86	13.3	0.49	0.04	0.08	0.01	5	90	592	0.0	0.94	0.49	0.01	0.29	0.5
Palai loamy clay SB 9478 A-D																				
0-20	7.5	9.8	0.76	41.7	47.5	(100)	30.8	16.2	0.29	0.20	0.01	19	89	353	0.8	1.43	0.56	0.01	0.24	1.4
20-35	7.4	3.0	0.16	15.2	19.4	(100)	15.3	4.0	0.01	0.11		8	92	363	<0.1	0.83	0.39	0.01	0.18	0.3
35-42	7.6	2.2	0.11	14.8	23.1	(100)	17.8	5.2	0.02	0.05	0.01	9	93	312	0.0	0.61	0.39	0.01	0.19	0.4
42-130	7.8	1.0	0.07	11.15	-- free lime --		5.1	0.02		0.06		5	92	335	1.0	0.58	0.51	0.01	0.11	0.3
Tafolomahina clay SB 9479 A-B																				
1-15	7.2	7.5	0.43	32.9	-- free lime --		9.6	0.21		0.17	0.01	11	91	409	1.0	1.68	0.53	0.01	0.46	4.6
15-46	7.6	2.3	0.13	0.02	(100)	11.0	4.2	0.03	0.04	0.01	0.0	6	95	265		0.82	0.47	0.01	0.38	0.3

Soil & Depth (cm)	pH	Organic Matter C%	N%	Cation exchange (me. %) CEC	∑ Bases	BS%	Ca	Mg	K	Na	Reserve Kc (me. %)	Ads S (ppm)	Phosphorus Retn (%)	0.5m H_2SO_4	$CaCO_3$ (%)	Tamm Oxalate Al (%)	Fe (%)	Si (%)	Na (%)	Extr Zn (ppm)
Toi silty clay SB 9473 A-C																				
0-15	7.3	10.3	0.71	50.1	58.7	(100)	47.0	10.80	0.53	0.33	0.02	17	81	764	0.3	1.58	0.52	0.02	0.26	1.9
15-30	6.9	7.7	0.49	33.2	35.5	(100)	31.0	4.00	0.19	0.30		10	90	693	<0.1	1.65	0.49	0.01	0.28	0.6
30-45	6.8	3.0	0.19	18.5	10.6	57	9.7	0.70	0.05	0.10	0.02	15	94	441	<0.1	0.10	0.35	0.01	0.23	0.3
Tumufa loamy clay SB 9476 A-B																				
1-10	7.3	7.7	0.49	30.5	-- free lime --		1.11	0.22		0.11	0.01	9	86	342	2.0	1.12	0.37	0.01	0.27	0.6
10-22	7.3	5.1	0.36	24.8	21.9	88	21.4	0.31	0.16	0.07	0.01	11	90	252	0.3	1.03	0.43	0.01	0.28	0.4
Vaiea loamy clay SB 9475 A-B																				
1-10	7.3	10.3	0.66	44.8	-- free lime --		4.6	0.28		0.16	0.01	13	86	567	2	2.1	0.51	0.01	0.45	1.4
10-20	7.6	6.9	0.67	37.9	-- free lime --		3.3	0.23		0.13	0.01	8	94	492	19	2.2	0.45	0.01	0.42	0.6

7.2 Physical properties

The results from analyses of physical analyses conducted at Soil Bureau, DSIR Laboratories, Taita, are presented in Table 7. They cover particle size and water-holding data for soils.

The particle-size analysis shows the amounts of sand, silt and clay in the soil after it is broken up into its primary particles. The soils are all very high in clay, but as the clay is very strongly tied together into larger aggregates it does not behave physically as a high-clay soil and has, for example, low bulk density (high pore space) and very high permeability to air and water. The soils are strongly structured and under good management are unlikely to be limited in performance by structural problems.

The water-holding properties are very important in soils that have seasonal water deficits. Two measurements are given:

1. Water content at 0.2 bar tension or approximately the amount of water in the soil when it is fully saturated and the excess has been allowed to drain off. This is "field capacity", indicating the ability of the soil to hold water against drainage by gravity.

2. Water content at 15 bar tension or approximately the amount of water in the soil when actively growing plants are unable to extract any more. This is "wilting point", indicating the ability of the soil to withhold water from active roots.

"Available water", the difference between the two measured figures, is thus the amount of water available to plants from a soil at "field capacity".

As an example, the horizon 18–28 cm (Au2 for Toi silty clay in Table 7) has 42.5% of its volume occupied by water when fully wet ("field capacity"). When so dry that plants are unable to obtain any more water from it, it contains 36.4% water. This is a lot of water, in fact in this 18–28 cm (Au2) horizon, which is 10 cm thick, the equivalent of about 39 mm of rainfall is held so strongly that plants cannot extract it. The amount of available water is 6.1%, equivalent to about ¼ inch of rainfall. It is not possible from the figures given to calculate accurately the available water for the whole profile but it is probably equivalent to about 30 mm of rainfall.

This kind of information is necessary when estimating the irrigation water needs of crops from rainfall and potential evapotranspiration, as the timing of water applications depends very much on the amounts of water that can be supplied by the soil during dry periods. The information supplied, however, does not tell us how much water can be supplied from the underlying limestone. This may be substantial, but requires further study to find the actual quantities.

7.3 Soil mineralogy

The clay minerals are those of strongly weathered soils and occur as mixtures of crandallite (a calcium aluminium phosphate), gibbsite (an aluminium oxide), and goethite (an iron oxide), with small amounts of related minerals.

The limestone rock is made up of calcite and aragonite (forms of calcium carbonate) and, in places, dolomite (a calcium magnesium carbonate) in varying proportions.

The composition of the minerals is consistent with the idea that Niue is formed from a raised coral island covered initially with volcanic ash deposits and later with extensive deposits of guano from sea birds. A long period of weathering under a tropical climate has broken down the primary minerals of the volcanic ash to those present today.

7.4 Conclusion

The soil chemical and physical properties have contributed greatly to the understanding of the nature and genesis of Niue soils, to determining soil classifications, and to the development of our knowledge of nutrient needs of crops. The information on water-holding capacities will be particularly useful when considering irrigation.

Table 7 Physical analysis

(a) Particle size

Soil and Depth (cm)	Stones >2mm %	Fine Earth >2mm %	Fine Earth Analysis Sand 2-0.05mm %	Silt 0.05-0.002mm %	Clay < 0.002mm %
Avatele stony loamy clay SB9471 A–C					
0–10	19	81	7	54	39
10–55		100	1	43	56
55–120		100	1	37	62
Fetiki clay not sampled					
Foa clay SB 9477 A-C					
0–18		100	3	30	67
18–33		100	0	18	82
33–98		100	0	15	85
Fonuakula clay loam SB 9474 A–E					
0–20	6	94	31	47	22
20–36	2	98	14	41	45
36–56	2	98	3	34	63
56–125		100	2	16	82
125–135	40	60	90	10	0
Hakupu loamy clay SB 9482 A–D					
0–12	7	93	6	47	47
12–28	3	97	6	47	47
28–42	1	99	3	55	42
42–70		100	1	37	62

Hikutavake loamy clay SB 9480 A–C					
0–19	2	98	6	38	56
19–32	3	97	6	41	53
32–48	3	97	2	39	59
Mutalau loamy clay SB 9472 A–C					
0–11	1	99	12	43	45
11–30	1	99	3	29	68
30–56		100	1	26	73
Niufela loamy clay SB 9481 A–C					
0–10	4	96	4	35	61
10–26	1	99	4	34	62
26–42		100	2	20	78
Palai loamy clay SB 9478 A–D					
0–20	13	87	7	36	57
20–35	4	96	6	44	52
35–42		100	3	34	63
42–130		100	0	14	86
Tafolomahina clay SB 9479 A–B					
1–15	2	98	5	33	62
15–46	4	96	1	35	64
Toi silty clay SB 9473 A–C					
0–15	2	98	13	48	39
15–30	2	98	9	28	63
30–45	1	99	1	38	61
Tumufa loamy clay SB 9476 A–B					
1–10	9	91	5	42	53
10–22	2	98	5	29	66
Vaiea loamy clay SB 9475 A–B					
0–10	12	88	9	43	48
0–20	12	88	8	27	65

(b) Water holding data, bulk density, porosity

Soil and Depth (cm)	Bulk Density mg/m^3	Total Porosity %	Large Pores %	Water Content with Tension at 0.02 bar (% v/v)	Water Content with Tension at 15 bar (% v/v)	Available Water (% v/v)
Foa clay SB 9477 A, C						
6–16	0.72	73.3	30.7	40.8	31.7	9.1
50–60	0.75	74.8	33.2	35.4	31.6	3.8
Fonuakula clay loam SB 9474 B–D						
24–34	0.64	79.4	46.7	30.2	23.6	6.6
40–50	0.78	75.1	29.2	36.7	27.5	9.2
80–90	0.75	74.7	29.5	35.9	27.8	8.1
Mutalau loamy clay SB 9472 B, C						
17–28	0.74	74.1	27.3	42.3	33.2	9.1
34–44	0.73	75.1	32.2	36.6	31.7	4.9
Niufela loamy clay SB 9481 B, C						
12–22	0.75	73.4	26.7	44.6	36.8	7.8
30–40	0.72	74.8	25.5	44.3	35.9	8.4
Palai loamy clay SB 9478 B, D						
22–32	0.69	75.8	33.7	39.8	29.4	10.5
63–73	0.57	80.7	37.2	34.5	26.8	7.8
Tafolomahina clay SB 9479 A-B						
2–12	0.78	73.4	26.5	44.1	35.9	8.2
20–30	0.75	68.2	23.6	44.1	35.7	8.4
Toi silty clay SB 9473 B, C						
18–28	0.76	73.0	26.3	42.5	36.4	6.1
32–42	0.63	78.4	24.3	38.9	29.8	9.1

8 Soil Fertility of Selected Soils

The agronomic research described here is based on field and glasshouse experiments conducted in 1978/79 by NZ Soil Bureau, DSIR (Widdowson 1980).

8.1 Introduction

In 1978 bulk samples of soil were collected from sites representative of the main soils of Niue. The bulk samples were shipped back to New Zealand, and experiments were carried out to assess the plant nutrient content of the soils. From these studies it was established which plant nutrients are deficient or potentially deficient for crop growth on each of the soils. In addition, the soils were chemically analysed to provide additional information on the nutrient content of the soils.

In this study the grass Green Panic, *Panicum maximum var. trichoglume*, was used to examine the response to the major nutrients, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and to the minor nutrients molybdenum, boron, copper, zinc and manganese using a subtractive technique. Green panic was grown in pots over a period of 4 months under glasshouse conditions that resembled the climate of Niue. In these experiments a subtractive design was used in which the complete or reference treatment receives a standard application of all essential nutrients, and each nutrient in turn is omitted from the complete treatment in the other treatments. In a subtractive treatment, for example, the –P treatment, Green Panic had all the nutrients except phosphorus and thus had to get its P from the soil in the pot.

The extent to which growth is limited therefore provides a measure of the deficiency or adequacy of phosphorus in the soil. Nutrient applications were made after the Green Panic was harvested and again after each harvest.

The temperatures in the glasshouse were 22–26ºC by day and 18–20ºC by night. Distilled water was added regularly to adjust the soil moisture content to field capacity.

The 8 treatments used on each soil are given in Table 8, which shows that all soil series have similar nutrient status and that all soils are deficient in nitrogen, potassium, and sulphur to about the same extent. Zinc deficiency tends to be more variable between soils. The nutrient status and extent of deficiency for all soils has been summarised in Figure 2. Nutrients such as phosphorus, manganese, and molybdenum are well-supplied in Niue soils and therefore give a high percent yield.

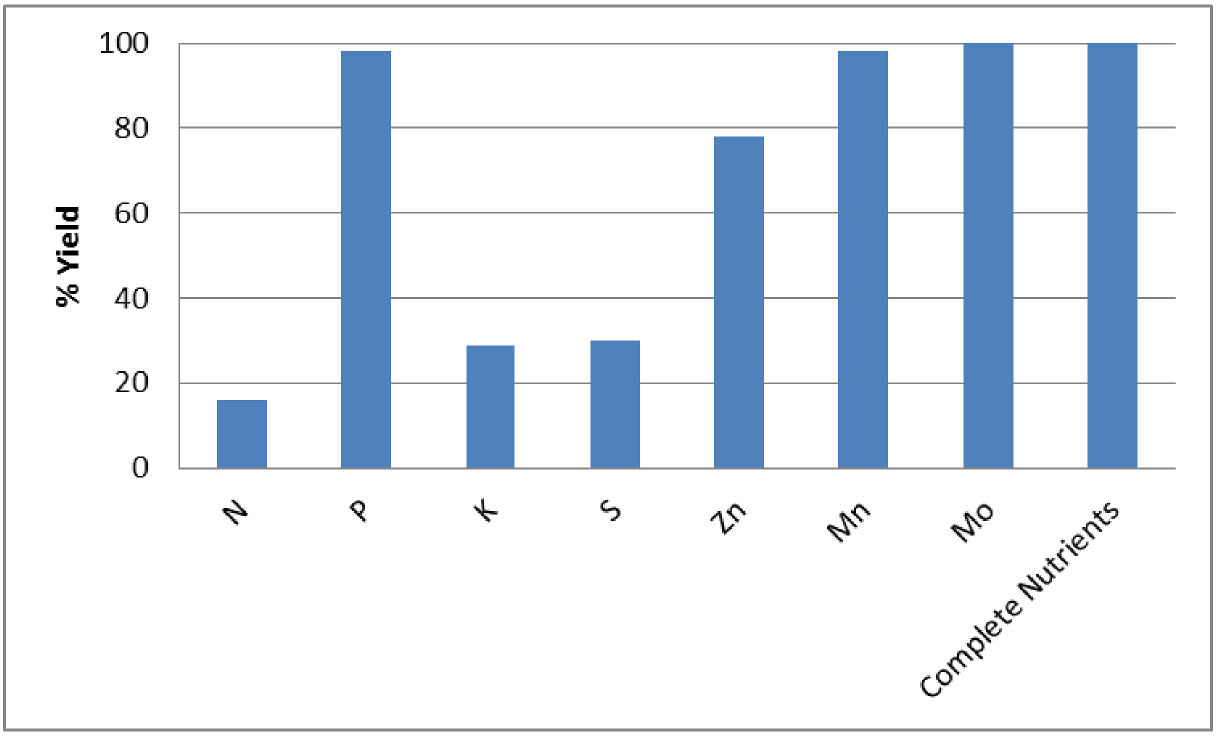


Figure 2 Yield of Green Panic, grown on various subtractive treatments relative to the complete Nutrient treatment (100) on Niue soils.
Data are based on dry matter yields for 8 representative topsoils over four harvests.

8.2 Fertility in tropical soils with reference to Niue

Normal (i.e. rapid) plant growth in the tropics requires, in approximate order of importance: (i) abundant soil moisture; (ii) a steady source of nitrogen (at a relatively high concentration); (iii) a steady source of potassium (at a relatively high concentration); (iv) a continuous supply of phosphorus (which can be at a relatively low concentration; (v) adequate calcium, magnesium and trace elements.

Most soils of Niue are free draining. The soil clays, very poor in clay minerals of the 2:1 expanding lattice type, are only moderately retentive of moisture so that the soils drain quickly and dry out rapidly.

The presence of large quantities of rock and stone on the soil surface, and the existence of pockets of soil in crevices and shallow depressions in limestone below the surface, help considerably in retaining water that might otherwise be lost by direct evaporation.

Nevertheless, when the precipitation falls below 10 cm per month for 2 or more successive months, plant growth on Niue is definitely affected by lack of available soil moisture; particularly where the soils are underlaid by makatea, i.e. Toi, Fonuakula, Vaiea, Niufela, and Tafolomahina soils. When rainfall falls below 5 cm for 2 or more successive months, all plants other than a few deep-rooted species on soils (Hikutavake, Avatele, Hakupu, Palai), are very markedly affected.

Some soils illustrate the serious losses of organic matter caused by burning forest residues and through past over-cultivation, and deterioration in soil fertility is very apparent; this stresses the retention of the traditional system of shifting cultivation. This deterioration of soil fertility is the result partly of worsening physical conditions (such as reduced soil moisture retention and modified soil structures), and partly due to the declining supply of plant nutrient elements – notably potassium, but probably also mineralisable nitrogen and phosphorus.

8.3 Interpretation of fertility experiments

From the pot experiments with Green Panic and the soil chemistry analysis, the following conclusions can be drawn on the nutrient status:

- Organic matter levels are quite high, especially after bush fallow
- Calcium carbonate enrichment dilutes the nutrient content of soils and by raising pH reduces the availability of such minor elements as Zn, Mn and Fe
- Available calcium, magnesium, and phosphorus are high in all soils and do not need to be supplied in fertilisers
- Available nitrogen increases in the soil under a bush fallow but will decline rapidly with cropping and must therefore be supplied by fertiliser
- Potassium levels are generally low and, while there is some increase during the bush fallow, potassium should be supplied in fertiliser for most cropping situations
- Available sulphur was quickly depleted by Green Panic in pot experiments but under field conditions there will be sufficient sulphur from the atmosphere (derived from sea spray) to satisfy crop needs
- Available zinc is low in most topsoils and declines to very low levels in the subsoil. Zinc should be supplied to most crops
- Manganese appeared to be adequate for Green Panic but uptake tends to be low in calcareous soils and spray applications of Mn, together with Zn, are recommended for most crops.

8.4 Diagnosis of nutrient deficiency

Diagnosis of a nutrient deficiency is now straightforward. First, consider the nutrient needs of the crop being grown. Most textbooks on crops give tables indicating the amounts of nutrients taken up by a crop in a year. By comparing the nutrient requirement for a given crop with amounts being supplied by the soil and that added as fertiliser, it is possible to decide on which nutrients may be lacking for good crop growth.

Several techniques are available for the assessment of nutrient deficiencies in crops.

8.4.1 Visual symptoms

Deficiencies of nutrients for many plant species produce visual symptoms on the leaves that are characteristic for a particular nutrient, e.g. a deficiency of iron in citrus appears as chlorosis (yellowing) of new terminal leaves with older leaves remaining green. Where deficiency is severe, leaves may become entirely yellow with only the mid-ribs remaining green. Deficiency systems in many plants are characteristic for nitrogen, potassium, sulphur, magnesium, iron, zinc, and manganese. Collect a range of leaves showing increasing severity of symptoms and refer to the internet for a description and pictures of symptoms for that particular crop.

8.4.2 Soil analysis

Chemical analysis of soils will provide a guide to the nutrient status of soils. The analyses in Chapter 7 explain much about the plant nutrient content of the soil and the likelihood of nutrient deficiencies. Such methods of chemical analysis are accurate but too costly for routine testing of growers' fields. Quick-test methods of soil analysis are designed for testing the nutrient status of growers' soils. It is important that the latter laboratories provide an interpretation of the results.

8.4.3 Foliar analysis

The chemical analysis of the leaves of plants at a defined stage of growth is often a useful means of assessing whether the nutrient needs of a crop are being met. As a means of assessing whether the crop is receiving an adequate supply of the minor nutrients – iron, manganese, zinc, copper, boron and molybdenum – it is probably the best method.

Foliar analysis is based on the premise that the amount of a given nutrient in a plant part is an indication of the supply of that particular nutrient. For each nutrient and each kind of plant there is a critical level above which there is luxury uptake of nutrient without increase in yield and below which there is a decrease in crop yield or performance. The use of foliar analysis does, however, require a detailed knowledge of the mineral nutrition of the crop being studied. The retention of the correct plant part, at the correct stage of growth, is most important if the results are to be meaningful. The critical nutrient content for a number of tropical crops has now been worked out so that foliar analysis can now be applied to a range of crops.

8.4.4 Pot experiments

Pot experiments with indicator plants allow the status of all nutrients to be examined under controlled conditions – a facility that cannot be done with confidence using soil analysis alone. In such experiments the plant is used as an extractant, rather than empirical solution, as in soil analysis. The simplest type of design – the subtractive method – is described in Section 8.1. Essentially this method consists of studying the presence and absence of a nutrient in the soil, keeping all other nutrients at an optimum level.

8.5 Soil moisture and potential for irrigation

Although the average relative humidity is high (89% at 9 am), the South-East trade wind blows steadily for most of the year. It is particularly reliable during the drier months of the year (May–October), blowing steadily at a mean speed of 3.6 m/second (Wright & Van Westerndorp 1965) for most of the day. This steady wind gives rise to fairly high evaporation rates in spite of the high relative humidity.

The soils of Niue have a very low water-holding capacity, ranging from 6 to 10 percent by volume. The reason for such a low water-holding capacity is twofold: first, the very high percentage of water held at permanent wilting point (15 bar) due to the high percentage of clay in the soils; second, the very low bulk densities of the soils resulting from their extremely well developed structures gives a high percentage of pore space (Table 7).

The predominantly shallow nature of the Niuean soils means that for any given area available to the plant there will be less moisture stored than would be the case in a deeper soil. In addition, this soil depth varies quite significantly over very short distances, for example, at one site topsoil depth was found to vary from 5 cm to 75 cm within a distance of two metres. Coupled with this variable soil depth is the large proportion of land surface comprised of rock outcrops; this has been estimated (Wright & Van Westerndorp 1965) at 40%; of the remaining 7800 ha of land covered by soil 44% can be classed as shallow, i.e. less than 30 cm depth.

The roots of plants tolerant of alkaline conditions will penetrate the soft “makatea” underlying many Niuean soils; however, on excavating limes and passionfruit their roots are found to penetrate only into those fissures and cracks in the limestone that have been filled with soil washed down the profile.

It would appear that for the foreseeable irrigation development there is ample water available in terms of both quantity and quality. However, the groundwater lens on which all Niue depends is an extremely fragile and precious resource. Given the extreme permeability of the soils and limestone, contamination of the lens is always a danger – the greatest risk of contamination is from nitrate in fertilisers. It was recommended that fertiliser usage be carefully overseen, and regular monitoring of the bore water is undertaken.

8.6 Soil fertility and pasture growth

Pasture plants need light, warmth, water, and minerals to grow. The first two are adequately provided on Niue in normal seasons, and water adequate in most seasons, but a balance of mineral nutrients is required for maximum plant growth.

The principal nutrients required by pasture plants are nitrogen, phosphorus, potassium, sulphur, and calcium among the major requirements, while copper, iron, zinc, boron, magnesium, and molybdenum are required in minor amounts. However, there is not always a clear relationship between the levels of these elements in the soil and their availability to plants and the actual levels of these elements in the growing plant. Too high a level of calcium (lime) can prevent copper and zinc being taken up by plant roots even when plenty is present in the soil.

Nitrogen is a special case. Naturally occurring nitrogen compounds soon become available from decay of plants under tropical conditions but they are soon washed out of the topsoil and are unavailable to plant roots. The same happens to nitrogen fertilisers applied to the surface of pastures. Although nitrogen stimulates grass growth it adversely affects legumes, which may later disappear from the pasture mixture. Nitrogen should therefore only be used for special purposes on pastures and the soil fertility adjusted to encourage legumes. These legumes will produce nitrogen in their roots and some of this nitrogen will be available to supply the needs of the companion grasses.

The only soil nutrient in very short supply for pastures is zinc. Potash and sulphur vary and may be low, but only under cut and carry (or haying) conditions or under coconuts are potash responses likely. No conclusive responses to sulphur or phosphorus have been recorded nor have any trace elements (except zinc) given pasture responses. Although nitrogen can enhance grass production its use, except under exceptional circumstances, will, in the long run, be more harmful than helpful due to the loss of legumes and the increased establishment of weeds in the pasture.

Appropriate control of pastures – spelling coconut pastures during the wet season and moderately hard rotational grazing – will ensure highest animal (and coconut) production and maintain lowest internal parasite burdens on the livestock. Under rotational grazing sufficient cattle should be used to pasture down to 10–15 cm stubble within a period of 4–6 days. Following grazing the pasture should be spelled for a period of 30–80 days dependent on climatic conditions.

Although many species of pasture plants have been evaluated in Niue, the most successful producers are the legume Siratro (*Macroptilium atropurpureum*) and the grass green panic (*Panicum maximum* var. *Trichoglume*). In combination they perform well in open pastures as well as under coconut palms where positive production is probably only half that produced in full light. Another possibility is alternate rows of *Leucaena leucocephala* and guinea grass (*Panicum maximum*), which probably has the world's highest yielding pasture combination.

Other legumes that have shown promise include *Desmodium intortum* cv. Green leaf and *Glycine* wightii cv. Tinaroo. Grass species that have proved to be palatable, productive, and persistent are *Setaria anceps* and the *Panicum maximum* varieties, Coloniao and Hamil.

Niuean farmers will have to learn to live with the problem of calcareous, high pH soils by applying trace elements, especially zinc, as acidification by sulphur or other fertiliser application is not a practical or economic proposition. Some alleviation of the problem may be obtained by the use of mulches to increase levels of soil organic matter.

Dale (unpublished report, 1981) suggested sowing rates for Siratro are 6.7 kg/ha of scarified seed and for green panic 0.6 kg/ha accompanied by zinc sulphate at 90–100kg/ha and, if required later, potassium sulphate or potassium chloride at 125250 kg/ha. For best uptake of zinc this fertiliser should be incorporated into the soil. However, every care should be taken not to incorporate makatea into the soil as the high liming effect restricts the availability of zinc in plants.

Table 8 Response of Green Panic to nutrient treatments

	Fonuakula loamy clay				Hukupu loamy clay				Niufela clay			
	Topsoil		Subsoil		Topsoil		Subsoil		Topsoil		Subsoil	
	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)
Complete nutrients	11.84		7.2		12.19		9.13		12.15		9.97	
Minus nitrogen	0.26	2	0.13	2	1.36	11	0.14	2	1.15	9	0.17	2
Minus phosphorus	11.69	99	4.65	64	11.60	95	8.96	98	12.03	99	9.40	94
Minus potassium	3.64	31	0.81	11	2.73	22	0.31	3	2.82	23	0.60	6
Minus sulphur	4.03	34	2.93	41	3.38	28	2.22	24	2.58	21	2.25	23
Minus zinc	8.09	68	3.44	48	7.52	62	4.02	44	10.24	84	4.84	49
Minus manganese	11.62	98	6.93	96	12.18	100	9.51	104	12.30	101	10.03	101
Minus molybdenum	12.40	105	7.06	98	11.79	97	9.62	115	12.24	101	9.84	99

	Palai clay				Tafolomahina clay				Tumufa clay			
	Topsoil		Subsoil		Topsoil		Subsoil		Topsoil		Subsoil	
	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)
Complete nutrients	12.24		9.04		12.25		6.97		11.87		7.45	
Minus nitrogen	1.50	12	0.21	2	1.87	15	0.29	4	2.24	19	0.73	10
Minus phosphorus	12.08	99	7.27	80	12.37	101	6.32	91	11.75	99	5.01	67
Minus potassium	3.26	27	0.77	9	3.43	28	1.10	16	4.37	37	2.56	34
Minus sulphur	3.10	25	1.16	13	4.24	35	1.98	28	3.65	31	1.98	27
Minus zinc	6.48	53	2.19	24	11.48	94	3.81	55	8.62	73	1.09	15
Minus manganese	12.34	101	9.20	102	11.74	96	6.95	100	12.39	104	6.41	86
Minus molybdenum	12.26	100	8.71	96	12.20	100	7.79	112	12.10	102	7.40	99

[1] Yield of dry matter from 4 harvests (grams/pot)

[2] Yield of dry matter from 4 harvests expressed as a percentage of the yield of the complete fertiliser treatment

Table 8 (con't)

	Vaiea loamy clay			
	Topsoil		Subsoil	
	Yield[1] (g)	Yield[2] (%)	Yield[1] (g)	Yield[2] (%)
Complete nutrients	11.83		5.71	
Minus nitrogen	1.07	9	0.19	3
Minus phosphorus	11.70	99	3.38	59
Minus potassium	4.20	36	0.85	15
Minus sulphur	4.61	39	2.79	49
Minus zinc	11.15	94	2.68	47
Minus manganese	11.96	101	5.43	95
Minus molybdenum	12.54	106	4.57	80

[1] Yield of dry matter from 4 harvests (grams/pot)

[2] Yield of dry matter from 4 harvests expressed as a percentage of the yield of the complete fertiliser treatment

9 Application of the Fertility Capability Soil Classification (FCSC)

9.1 The system

Soil classification systems, e.g. Soil Taxonomy, place more emphasis on subsurface than on topsoil properties, because of their permanent nature, whereas most soil management practices are largely limited to the plough layer.

FCSC is the first technical soil classification that groups soils according to their fertility constraints in a quantitative manner.

The term "topsoil" refers to the plough layer or the top 20 cm of the soil, whichever is shallower. The term "subsoil" encompasses the depth interval between the topsoil and 60 cm depth.

Three categorical levels are presented: type (texture of the surface soil layer), substrata type (subsoil texture), and modifiers.

9.2 Type

Type, the highest category, is determined by the texture of the plough layer, or upper 20 cm of the soil, whichever is shallower. Four textural types are defined (code letters indicative of type are capitalised):

G = Gravelly topsoils	:	They have more than 20% by volume of gravels, stones, rock fragments
S = Sandy topsoils	:	Loamy sands and sands
L = Loamy topsoils	:	They have <35% clay, but are not loamy sand or sand
C = Clay topsoils	:	They have >35% clay

9.3 Substrata type

Used if textural change or a hard root restricting layer is encountered within 50 cm.

R = Rock or other hard root restricting layer

G = Gravelly subsoil	:	As described above
S = Sandy subsoil	:	Texture as above
L = Loamy subsoil	:	Texture as above
C = Clayey subsoil	:	Texture as above

9.4 Condition modifiers

These refer to chemical and physical properties of the plough layer or top 20 cm, whichever is shallower. The modifiers indicate specific fertility limitations with different possible interpretations.

Letter-coding of the condition modifiers are given as lower case letters, which have been selected to provide easy association with the conditions described.

The criterion listed first is the most important one. The condition modifiers or Niue soils are:

d = (dry)
Ustic soil moisture regimes (subsoil dry for more than 90 cumulative days per year within 20–60 cm depth)

e = (Low CEC)
Low cation exchange capacity (CEC)

h = (Acid)
pH values between 5.0 and 6.0, i.e. strongly to moderately acid

i = (Fe-P fixation)
High phosphorus fixation by iron. Hues redder than 5YR and with a granular structure

p = (Low available P)
Low available phosphorus within 50 cm of the soil surface

k = (K deficient)
Exchangeable potassium <0.20%/100gm

b = (Basic reaction)
Free $CaCO_3$ within 50 cm (effervescence with HCL) or pH values >7.3

The assessment of Niuean soils according to FCSC criteria are given below in Table 9.

Table 9 Fertility Capability Soil Classification applied to Niue Soils

Soil Series	FCSC Unit
Avatele	GCdib
Fetiki	CCdik
Foa	CCdik
Fonuakula	LCdikb
Hakupu	CCdi
Hikutavake	CRdikb
Mutalau	CSdikb
Niufela	CSdik
Palai	CCdikb
Tafolomahina	CSdik
Toi	CSdi
Tumufa	CSdik
Vaiea	CSdik

9.5 Interpretation of the FCSC units

Though FCSC units present different management problems, these can be inferred from the type, substrata type and modifiers:

G: high compaction, low infiltration, low water-holding capacity, ploughing limitations, low nutrient content, always dry

S: high rate of infiltration, low water-holding capacity

L: medium infiltration rate, good water-holding capacity

C: low infiltration rate, good water-holding capacity, potential high run-off if sloping, difficult to till except when "i" modifier is present (i.e. "Ci" soils are easy to till, have high infiltration rates and low water-holding capacity)

R: hard rock, root penetration impossible.

9.6 Interpretation of modifiers

When only one modifier is included in the FCSC unit, the following designated limitations or management requirements apply to the soil; however, interpretations may differ when two or more modifiers are present simultaneously or when textural types are different:

d: Moisture is a limitation during the dry season unless soil is irrigated. Planting date should take into account the flush of N at onset of rains, and germination problems are often experienced if first rains are sporadic e: Low ability to retain nutrients against leaching, mainly K, Ca and Mg. Heavy applications of these nutrients and of N fertilisers should be split, potential danger of over-liming

h: Low to medium soil acidity; requires liming for Al-sensitive crops

i: High P-fixation capacity, requires high levels of P fertiliser or special P management practices. Sources and method of P fertiliser application should be considered carefully. With C texture, these soils have granular soil structure

p: Low available P; P-fertiliser is required for plant growth

k: Low ability to supply K. Availability of K should be monitored, and K fertilisers may be required frequently; potential K-Mg-Ca imbalance

b: Calcareous soils. Rock phosphate and other non-water-soluble phosphates should be avoided. Potential deficiency of certain micronutrients, principally iron and zinc.

9.7 Sample interpretation of FCSC nomenclature

GSdib High compaction, low water-holding capacity, cultivation limitations, low nutrient content, commonly dry (GS). Moisture is a limitation during the dry season unless soil is irrigated (d). High P-fixation capacity and there can be some limitations of P availability, although P figures are very high for all Niue soils (i). Calcareous soils, potential deficiency of certain micronutrients, e.g. zinc (b).

9.8 Analysis of Niue FCSC units

FCSC units are grouped according to the type, substrata type and modifier, and given in Table 10. The soils of Niue are very similar in their chemical properties. Phosphorus retention figures are very high, suggesting some limitations of P availability, but the retention at neutral pHs is largely by calcium and the P therefore appears to be available in adequate quantities for crops. Levels of K are generally low or very low. Zinc is generally low.

Table 10 Analysis of type, substrata type, and modifier for FCSC units

Type	Substrata Type	Modifier
C – 11	C – 6	d – 13
G – 1	S – 6	i – 13
L – 1	R – 1	k – 10
		b – 4

10 Soil Limitations

The Niuean soils exhibit a very similar set of soil limitations, differing in the degree of rock outcrops, surface stoniness, profile limitations, stoniness and boulders, and soil shallowness.

All soils have the limitations of having low water-holding capacities and moderate to rapid permeabilities, which, combined with low rainfall in the months of May through to October in most years, see all soils experiencing seasonable soil moisture deficits (ustic soil moisture regime).

They all have nutrient deficiencies – calcium carbonate enrichment dilutes the nutrient content of soils and, by raising pH values, reduces the availability of such minor elements as zinc, manganese, and iron. Potassium levels are generally low. The amount of Kc or reserves of potassium that can in future become available from weathering, are negligible and potassium should be supplied in fertiliser for most cropping situations. Soils have very high phosphorus retention but high phosphorus reserve. Available zinc is low in most topsoils and declines to very low levels in the subsoil and zinc should be supplied to most crops – in the planting hole. Manganese uptake tends to be low in calcareous soils and spray applications of Mn would be recommended for most fruit crops.

Tafolomahina, Tumufa, Niufela, and Vaiea soils have the limitation of shallowness, i.e. depth to makatea or coral reef rock, while Hikutavake, Mutalau, and Niufela soils have significant coralline stones and often with boulders in soil profiles.

Hakupu, Hikutavake, Mutalau and Vaiea soils have the additional limitation of surface stones (>20%) that is a limiting factor for cultivation.

Rock outcrops are also a serious limitation for cultivation, although there are commonly pockets of deeper soils between the coralline pinnacles. Eight soils show significant outcropping rocks – Avatele, Fetiki, Foa, Hakupu, Hikutavake, Mutalau, Niufela, and Palai.

11 Land and Soil Attributes Significant for Crop Growth

11.1 Introduction

The process of interpreting basic soil survey and laboratory characterisation of soils data through the key steps of assessing suitability of soils for crop production requires a compilation of soil attributes significant for crop growth into an easy-to-read format. The technical detail for the soils is available elsewhere, viz. Leslie (1986b).

The extended legend (Table 11 below) presents information in a format that can be easily used by extension officers, planners, etc., to promote agro-production with growers and agribusiness operations.

To give interpretative background to the columns in the extended legend, explanatory notes follow. Note, the first column is the soil series name and symbol as it appears on the soil map (Leslie 1986a).

11.2 Slope microrelief

Slope class and range of slopes is given in terms of slope classes defined by Taylor and Pohlen (1979):

- Flat to gently undulating (0–3º)
- Undulating (4–7º)
- Easy rolling (8–11º)
- Rolling (12–15º)
- Strongly rolling (16–20º)
- Moderately steep (21–25º)
- Steep (26–35º)
- Very steep (>35º)

11.3 Outcrops and surface stones and boulders

Rock outcrops and surface boulders and stones influence access and workability in the case of mechanisation. In the extended legend the percentage of the ground surface of the site occupied has been estimated:

(i) Rock outcrops: *In situ* bedrock that protrudes through the soil.

(ii) Boulders: Detached rock masses with diameters of more than 200 mm.

11.4 Overall drainage

Gives the overall drainage class for the soil and is based on those given by Taylor and Pohlen (1979). The classes are defined by the frequency and duration of wet periods and the speed at which water is removed from the soil. The soil drainage classes are: very poorly drained; poorly drained; imperfectly or somewhat poorly drained; moderately well drained; well drained; somewhat excessively drained; and excessively drained. The class refers to natural drainage conditions prevailing at sites at which the soil occurs.

11.5 Profile textural pattern

Describes any variations in horizon thickness, soil colour, and soil texture within the profile to a soil depth of 120 cm. The thickness (cm) and depth (cm) from the soil surface of the different horizons are described. The texture classes are defined as follows:

(i) classes with less than 18% clay:

- sand: 80% or more sand and 8% or less clay
- loamy sand: less than 80% sand, 8% or less clay, and less than 40% silt
- sandy loam: more than 8% clay and less than 40% silt
- loamy silt: between 40% and 82% silt
- silt: more than 82% silt

(ii) classes with 18–35% clay:

- sandy clay loam: 15% or less silt
- clay loam: more than 15% and less than 40% silt
- silt loam: 40% or more silt

(iii) classes with more than 35% clay:

- silty clay: less than 60% clay and 30% or more silt
- loamy clay: less than 60% clay and less than 30% silt
- clay: 60% clay or more

A size qualifier – coarse, medium, fine – may be used as a prefix in sand, loamy sand, sandy loam, and sandy clay loam soil texture classes.

11.6 Minimum effective rooting depth

Effective rooting depth describes the soil volume available for plant roots to penetrate and take up water, nutrients, etc., and to give stability to the plant.

On compact rock the volume of soil penetrated by roots is limited by soil depth, though a few roots can break out through cracks and fissures. On loose or weathered rocks and alluvium, e.g. gravels, sands, etc., roots penetrate beyond the soil.

Ease of rooting depends primarily on soil structure, texture and consistence. Iron pans, concretions, very thick clay rich horizons, high water tables (can be seasonal) or impeded drainage, salinity, etc., can confine roots to only part of the soil. Depths to the impediment are given and the nature of the feature controlling this, e.g. high water table, aluminium toxicity, low nutrient status, etc., is described.

A soil on which roots penetrate to only 10 cm would be described as very shallow, 10–25 cm; shallow, 25–50 cm; medium, 50–100 cm deep; and over 100 cm as very deep rooting. The depth to which roots penetrate also depends, obviously, on the type of plant.

11.7 Susceptibility to drought

Describes the probability in normal years for moisture deficits to be experienced in soils. The soil moisture deficit and the period (months) in the year when deficits occur is given.

The annual rainfall range is given for each soil map unit.

11.8 Acidity/Alkalinity

Soil reaction, the intensity of soil acidity or alkalinity is an indicator of many other soil qualities. It is expressed in units of pH where pH7 is neutral, lower values indicate acidity, and higher values alkalinity. The general terms for describing the range of pH are:

Extremely acid	<4.5	Slightly alkaline	7.1 – 7.5
Strongly acid	4.5 – 5.2	Mod. alkaline	7.6 – 8.3
Mod. acid	5.3 – 5.9	Strongly alkaline	8.4 – 9.0
Slightly acid	6.0 – 6.5	Extremely alkaline	above 9.0
Near neutral	6.6 – 7.0		

Acidity of alkalinity status is given for whole soil profile or, where there is variation, for the individual horizon(s) with soil depths.

11.9 Known limiting nutrients

An important outcome of national soil survey and full characterisation of soils is to make as good an estimate as possible of the fertility of the soil series recognised. A fertile soil may be defined as one whose properties enable it to grow good crops over a long period of time, and soil fertility is the attribute of a soil concerned with its capacity to grow productive crops.

Based on laboratory analyses designed to fully characterise soils and facilitate soil classifications, those soil attributes of relevance to soil fertility were also derived. The key soils attributed limiting crop production considered were:

Cation-exchange properties (exchange capacity – CEC; base saturation; exchangeable bases – calcium, magnesium, potassium and sodium); organic carbon; total nitrogen; extractable phosphorous; zinc and potassium reserve.

11.10 Explanation of abbreviations

Soil colour:	
blk	black
br.	brown
dk	dark
dsk.	dusky
gr.	grey
lg.	light
pl.	pale
rd	red
wt.	white
yllw	yellow

Nutrients:	
K	potassium
P	Phosphorus

Table 11 Extended Legend: Land and soil attributes significant for crop growth

Soil (Symbol)	Slope, Microrelief	Outcrops and surface stones and boulders	Overall drainage	Profile textural pattern	Min. effective rooting depth	Susceptibility to drought	Acidity/ Alkalinity	Known Limiting Nutrients
Avatele (Av)	Flat to gently undulating (0-3º). Uneven surface.	10% coral rock outcrops. Common surface stones and boulders.	Well drained	0-10cm dk br. stony loamy clay 10-55cm dk br. loamy clay 55-120cm dk br. loamy clay *on* coral reef rock	<120cm	In normal years soil moisture deficits >90 days are experienced some time in the period May to October.	Slight to moderately alkaline.	Very high P retention (high P reserve); very low K reserve; subsoil zinc deficiency.
Fetiki (Ft)	Flat to gently undulating (0-3º). Even microrelief.	30-40% coral rock outcrops. Common small coral surface stones.	Well drained	0-20cm dk rd br. clay 20-33cm dsk. rd clay 33-58cm dk rd clay *on* coral reef rock	<60cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Not sampled. Likely to be slight to moderately alkaline.	High P retention (high P reserve); low K reserve; zinc deficiency.
Foa (Fo)	Flat to easy rolling (0-5º). Uneven microrelief.	30-60% coral rock outcrops. 10-30% coral surface stones.	Well drained	0-18cm dk rd br. clay 18-33cm dk rd br. clay 33-98cm dk rd clay *on* coral reef rock	<100cm	In normal years soil moisture deficits >90 days are experienced some time in the period May to October.	Slightly alkaline.	Very high P retention (high P reserve); low K reserve; zinc deficiency.
Fonuakula (Fk)	Flat to gently undulating (0-3º). Even microrelief.	No outcrops and surface stones and boulders.	Well drained	0-20cm dk rd br. clay loam 20-36cm dk rd br. loamy clay 36-56cm yllw rd loamy clay 56-125cm yllw rd clay *on* cemented coarse sand (makatea)	<125cm	In normal years soil moisture deficits >90 days are experienced some time in the period May to October.	Topsoil moderately alkaline, subsoil neutral.	High P retention (high P reserve); very low K reserve; zinc deficiency.
Hakupu (Hp)	Easy rolling (2-5º). Uneven microrelief.	80% coral rock outcrops. 30% coral surface stones.	Well drained	0-12cm dk rd br. loamy clay 12-28cm dk br. loamy clay 28-42cm dk rd br. loamy clay 42-70cm yllw rd clay *on* coral reef rock	<70cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline and moderately alkaline in subsoil.	Very high P retention (high P reserve); very low K reserve; zinc deficiency.
Hikutavake (Ht)	Flat to easy rolling (0-5º). Moderately steep to very steep (25-45º). Very uneven microrelief.	50% coral rock outcrops. Common surface stones.	Well drained	0-19cm dk br. loamy clay 19-32cm dk rd br. loamy clay 32-48cm yllw rd loamy clay *on* coral reef rock	<50cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline and moderately alkaline in subsoil.	Very high P retention (high P reserve); low K reserve; zinc deficiency.
Mutalau (Mu)	Undulating to easy rolling (2-5º). Uneven microrelief.	25-60% coral rock outcrops. 20-40% coral surface boulders and stones.	Well drained	0-11cm dk rd br. loamy clay 11-30cm dk rd br. clay 30-56cm rd br. clay 56-100cm stony very coarse sand (makatea)	<60cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline and moderately alkaline in subsoil.	Very high P retention (high P reserve); very low K reserve; zinc deficiency.

Soil (Symbol)	Slope, Microrelief	Outcrops and surface stones and boulders	Overall drainage	Profile textural pattern	Min. effective rooting depth	Susceptibility to drought	Acidity/ Alkalinity	Known Limiting Nutrients
Niufela (Ni)	Flat to gently undulating (0-3º). Flat even microrelief.	20% coral rock outcrops.	Well drained	0-10cm dk br. clay 10-26cm dk rd br. clay 26-42cm dk rd br. clay 42-100cm stony very coarse sandy loam (makatea)	<50cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline and moderately alkaline in subsoil.	Very high P retention (high P reserve); low K reserve; zinc deficiency.
Palai (Pa)	Flat to easy rolling (0-5º). Even microrelief between rock outcrops.	65% coral rock outcrops.	Well drained	0-20cm dk rd br. loamy clay 20-35cm dk rd br. loamy clay 35-42cm dk rd clay 42-120cm dk rd br. clay *on* coral reef rock	<120cm	In normal years soil moisture deficits >90 days are experienced some time in the period May to October.	Topsoil slightly alkaline and moderately alkaline in subsoil.	Very high P retention (high P reserve); very low K reserve; zinc deficiency.
Tafolomahina (Ta)	Flat to gently undulating (0-2º). Even microrelief.	10% coral surface stones.	Well drained	0-1cm dk rd br. iron nodules 1-15cm dk rd br. clay 15-46cm dk rd br. clay 46-152cm wt. very coarse sandy loam (makatea) *on* coral reef rock	<50cm	In normal years soil moisture deficits >120 days are experienced some time in the period.	Topsoil slightly alkaline and moderately alkaline in subsoil.	High P retention (high P reserve); low K reserve; zinc deficiency.
Toi (To)	Flat to gently undulating (0-2º). Even microrelief.	20% surface coral stones.	Well drained	0-15cm dk br. silty clay 15-30cm dk br. loamy clay 30-45cm dk rd br. loamy clay *on* wt. stony very coarse sand (makatea)	<50cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline and neutral in subsoil.	High P retention (high P reserve); low K reserve; zinc deficiency.
Tumufa (Tu)	Flat to gently undulating (0-2º). Even microrelief.	Surface Fe nodules.	Well drained	0-1cm yllw rd iron concretions and nodules 1-10cm dk rd br. loamy clay 10-22cm dk rd br. clay 22-120cm lg. gr. bouldery, stony and shelly sand (makatea)	<25cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline (subsoil not sampled).	Very high P retention (high P reserve); very low K reserve; zinc deficiency.
Vaiea (Va)	Flat to gently undulating (0-3º). Uneven microrelief.	20% surface coral stones.	Well drained	0-10cm dk br. loamy clay 10-20cm dk br. clay 20-120cm pl. yllw bouldery and stony coarse sand (makatea)	<25cm	In normal years soil moisture deficits >120 days are experienced some time in the period May to October.	Topsoil slightly alkaline (Au1) and moderately alkaline (Au2).	Very high P retention (high P reserve); very low K reserve; zinc deficiency.

12 Matching Land Qualities of Soil Units with Crop Requirements

12.1 Introduction

The interactions between elements of the soil-plant-atmosphere system that form the basis for crop production and management are complex.

Matching is the process of comparing the requirements of a particular crop with the diagnostic soil attributes of a particular soil.

The process initially involves concisely characterising soils in terms of a selected number of attributes deemed to be important for crop production and management.

Values of the soil characteristics for the soil series were derived from the data compiled for the 1:50 000 scale soil survey of Niue Island (Leslie 1986a) and described in the Soil Taxonomic Unit Descriptions (Leslie 1986b). The key soil and climate attributes used in the crop suitability analysis are given in Table 12.

It was decided to adopt a manual approach for calculating the performance of crops – a semi-quantitative description of plant/agro-ecological relationships and their use for estimating crop performance. This manual approach produced robust results and provided credible estimates for the crop suitability for crops matched with soil attributes for the soils mapped for Niue.

12.2 Issues relevant to crop suitability evaluations

Before discussing the crop matching and crop suitability evaluations it seems important to summarise some of the issues and assumptions made in conducting the process:

12.2.1 Soil limitations:

- Climate, in particular tolerance to a pronounced dry season, and uneven rainfall distribution (important for fruit set).
- Low water-holding capacity increasing susceptibility to drought during the dry season.
- Alkalinity. Selected crops must have a tolerance to neutral to slightly alkaline (pH 6.9 – 7.9) soils.
- Soil nutrient availability. All soils are very low in potassium and have a low potassium reserve; organic matter values are low, particularly nitrogen, except when following fallow periods or after forestry clearance, and rapidly declines with cropping; Sulphur values were low in glasshouse experiments but S should be regularly replenished by sea spray; and alkalinity drives manganese, iron and, importantly, zinc values down. Phosphorus, calcium and magnesium values are high.
- Surface rock outcrops and stoniness and, for some soils, profile stoniness.

- Irregular soil depths have a significant influence on the available minimum rooting depths most crops require. These preclude small plantation plantings and necessitate selecting the deeper "pockets" of soil (overlying coral rock or makatea) as the only option for the majority of soils.

12.2.2 Fertility:

- Soils on land cleared from forest or that have been fallow for a period of time will have high organic matter values, but these deplete rapidly, particularly nitrogen after a year of cropping. Also, burning of forest waste is not recommended. In addition to potassium deficiencies and due to the alkalinity there are element deficiencies, i.e. zinc, which, without fertiliser, results in marked chlorosis, for example, in limes.
- The fernland community or "desert" so described by Wright and van Westerndorp (1965) occupies large areas of the central basin. The fernland is thought to be the result of prolonged over-cropping and subsequent soil impoverishment; of relevance is that Niueans once mostly lived in these inland areas.
- Sykes (1970) describes widespread poor quality fruits from wild growing plants, i.e. mango, nonu, guava, etc. With fertilisation and sound management, quality, good-sized fruits are possible. These interventions apply for the majority of crops in Tables 15, 16, 17 and 19.

12.2.3 Marketing, processing and land use options:

- Given that shipping (and aircraft transport) from Niue limits what products can be economically exported, raises the question of whether there are overseas markets for the products?
- There is scope to identify crops having real market opportunity given processing in Niue to add value to the product.
- Some of the land-use options available include pastoralism, and a few forage crops have been included in the crops evaluated and pasture species, i.e. siratro, leucaena, etc., could be assessed should pastoralism be considered. Also, tree species that are potential biofuel plants are often also suitable for land restoration (e.g. fernlands).
- The domestic market is of significant importance for fruits and vegetables. With the small Niuean population, while recognizing tourism is important, it is crucial that local growers cooperate and stagger their crop production so as to avoid market lows and gluts and ensure even profitability to the growers throughout the year.
- A number of the indigenous fruit trees evaluated also have value for timber.

12.3 Process for determining crop suitability ratings

The methodology for determining the crop suitability ratings are as follows:

- Select crops to be evaluated. These were determined by Niue DAFF.
- Compile a data sheet for each crop documenting the range of growing conditions for the climate/soil attributes and land qualities.
- Based on land qualities and land characteristics (Table 12) compile data sheets for each soil (not published) to determine the primary crop needs before matching with the climatic data and the soil attributes.
- Derive crop suitability class (4 classes) for each soil noting soil limitations and input needs and indicative costs required for optimum production.
- Compile the crop and timber species suitability assessments into spreadsheets.
- Generate (by GIS) grouped suitability maps.

A future objective for the Department of Agriculture could be to determine a range of quantitative yields for each crop suitability assessment.

By matching crop requirements with land characteristics indicative suitability ratings for specific crops can be determined for each soil series.

The results of the analyses of matching the soils with the forest species, pasture and crops are in Tables 14, 15, 16, 17, 18 and 19.

- Crop suitability ratings for forest tree species (Table 14)
- Crop suitability ratings for fruits and vegetables (Table 15)
- Crop suitability ratings for important plants, fruit and nut trees (Table 16)
- Crop suitability ratings for root crops (Table 17)
- Suitability ratings for pasture species (Table 18)
- Crop suitability ratings for important plants and commercial tree crops (Table 19)

The type of land characteristics for the above crops required for optimal production is given in Table 12.

Three illustrations of the type of land quality/characteristic for each crop required for optimal production are given in Table 13.

Table 12 Key soil and climate attributes used in the crop suitability analysis

Land qualities	Land characteristics/attributes
Temperature	Mean max-temperature Mean min-temperature
Erosion hazard	Slope Soil erodibility
Moisture conditions	Mean annual rainfall Rainfall seasonality Soil texture (topsoil, subsoil) Landform
Potential for mechanization	Stoniness/rockiness Slope Topsoil texture
Rooting conditions	Effective soil depth Soil texture (topsoil, subsoil) Stoniness/rockiness
Nutrient availability/ Retention capacity	pH CEC Topsoil texture Anion fixation
Oxygen availability	Soil drainage
Soil toxicities	Calcium carbonate

Table 13 Selected illustrations of some land characteristics required by individual crops for optimal production

a. Lime

	Optimal		Absolute	
	Min.	**Max**	**Min.**	**Max**
Temperature requirement	23°	30°	13°	42°
Rainfall (annual)	1200mm	1600mm	450mm	2700mm
Latitude	-	-	35	44
Soil pH	5	6.5	4	8
Light intensity	very bright	very bright	very bright	clear skies
Soil depth	deep (>150cm)		medium (50–150 cm)	
Soil texture	medium, light		heavy, medium, light	
Soil fertility	moderate		low	
Soil drainage	well (dry spells)		well, excessive (dry spells)	

b. Sweet potato

	Optimal		Absolute	
	Min.	**Max**	**Min.**	**Max**
Temperature requirement	18°	28°	10°	38°
Rainfall (annual)	750mm	2000mm	350mm	5000mm
Latitude	-	-	32	40
Soil pH	5	7	4	8.7
Light intensity	very bright	very bright	very bright	clear skies
Soil depth	medium (50–150 cm)		shallow (20–50 cm)	
Soil fertility	high		low	

c. Vanilla

	Optimal		Absolute	
	Min.	**Max**	**Min.**	**Max**
Temperature requirement	21°	30°	10°	33°
Rainfall (annual)	2000mm	2500mm	1500mm	3000mm
Latitude	-	-	20	25
Soil pH	5.5	7	4.3	8
Light intensity	light shade	light shade	heavy shade	cloudy skies
Soil depth	shallow (20–50 cm)		shallow (20–50 cm)	
Soil texture	medium, organic		medium, light	
Soil fertility	high		moderate	
Soil drainage	well (dry spells)		well (dry spells)	

A four-class rating system for assessing the general effect of soil and climate attributes on optimum crop production has been applied under this system.

Class 1 **Highly suitable**

No significant limitations. Soils that are expected to be highly productive for the defined crop.

Class 2 **Moderately suitable**

Limitations reduce crop yields by 15–40% and/or increased recurrent costs for production and maintenance. Soils that are expected to be moderately productive for the defined crop.

Class 3 **Marginally suitable**

Soils that are expected to have a low productivity for the defined crop. Limitations reduce crop yields by 40–70% and/or considerably increase recurrent costs for production and maintenance.

Class 4 (N) **Not suitable**

Soils with very severe limitations that cannot be economically corrected.

Production is used here to mean production for commercial cropping (minimum area 0.5 ha) rather than subsistence farming.

The crop suitability ratings for soils are given in Tables 15, 16, 17 and 19.

Table 14 Crop suitability ratings for forest tree species

Soil	Acacia mangium	Agathis robusta	Alphitonia zizyphoides (Toi)	Casuarina equisetifolia (Toa)	Eucalyptus camaldensis	Pinus caribbaea spp. hondurensis	Santalum yasi (Sandalwood)	Swietenia macrophylla (Mahogany)	Swietenia mahogany (Mahogany)	Syzygium inophylloides (Kafika)	Toona australis
Avatele	1	1	2	1	1	2	1	1	2	1	2
Fetiki	2	2	3	2	2	3	2	2	3	2	3
Foa	1	1	2	1	1	2	1	1	2	1	2
Fonuakula	1	1	2	1	1	2	1	1	2	1	2
Hakupu	2	2	3	2	2	3	2	2	3	2	3
Hikutavake	3	3	N	3	3	N	3	3	N	3	N
Mutalau	3	3	3	3	3	3	3	3	3	3	3
Niufela	2	2	3	2	2	3	2	2	3	2	3
Palai	1	1	2	1	1	2	1	1	2	1	2
Tafolomahina	3	3	N	3	3	N	3	3	N	3	N
Toi	2	2	3	2	2	3	2	2	3	2	3
Tumufa	N	N	N	N	N	N	N	N	N	N	N
Vaiea	N	N	N	N	N	N	N	N	N	N	N

* No data available for timber species requirements for growth

Table 15 Crop suitability ratings for fruits and vegetables

Soil	Banana / Plantain	Beetroot	Bele	Carrot	Chinese cabbage	Capsicum	Cucumber	Eggplant	Green pea	Head cabbage	Lettuce	Long beans	Onion	Papaya	Passionfruit	Peanut	Pineapple	Pumpkin / Squash	Radish	Rockmelon	Silver beet	Soya bean	Spinach (local)	Spring onion	Sweet corn	Tomato	Vanilla	Watermelon	Zucchini
Avatele	2	1	2	1	1	2	2	2	1	2	2	1	1	2	2	2	2	1	1	1	2	1	2	1	1	2	2	1	1
Fetiki	2	1	2	1	1	2	2	2	1	2	2	1	1	2	2	2	2	1	1	1	3	1	2	1	1	2	2	1	1
Foa	2	1	2	1	1	2	2	2	1	2	2	1	1	2	2	2	2	1	1	1	2	1	2	1	1	2	2	1	1
Fonuakula	2	1	2	1	1	2	2	2	1	2	2	1	1	2	2	2	2	1	1	1	2	1	2	1	1	2	2	1	1
Hakupu	3	1	3	1	1	2	2	2	1	3	3	1	1	2	3	3	2	1	1	1	2	1	3	1	1	2	3	1	1
Hikutavake	3	2	3	2	2	3	2	2	2	3	3	2	2	2	3	3	3	2	2	2	3	2	3	2	2	3	3	2	2
Mutalau	3	1	3	1	1	3	3	3	1	3	3	1	1	2	3	3	3	1	1	1	3	1	3	1	1	3	3	1	1
Niufela	3	2	3	2	2	3	2	2	2	3	3	2	2	2	3	3	3	2	2	2	3	2	3	2	2	3	3	2	2
Palai	2	1	2	1	1	2	2	2	1	2	2	1	1	2	2	2	2	1	1	1	2	1	2	1	1	2	2	1	1
Tafolomahina	3	2	3	2	2	3	3	3	2	3	3	2	2	2	3	3	3	2	2	2	3	2	3	2	2	3	3	2	2
Toi	2	2	3	N	2	3	2	2	2	3	3	2	2	2	3	3	3	2	2	2	3	2	3	2	2	3	3	2	2
Tumufa	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Vaiea	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 16 Crop suitability ratings for important plants, fruit and nut trees

Soil	Breadfruit (Mei)	Canarium (Ai)	Coconut (Niu)	Cocoa	Coffee	Grapefruit	Guava (Kautoga)	Lemon	Lime (Sipolo Tahiti)	Lime (Sipolo Niue)	Lychee	Mandarin	Mango	Mountain apple	Neem	Orange	Polynesian plum	Rambutan	Soursop	Starfruit (Tapanima)	Sweetsop	Tahitian chestnut	Tamarind (Tamaline)	Tropical almond
Avatele	1	1	1	2	1	2	1	2	2	2	1	2	1	2	1	2	2	2	1	2	1	1	1	1
Fetiki	1	1	1	2	1	2	1	2	2	2	1	2	1	2	1	2	2	2	1	2	1	1	1	1
Foa	1	1	1	2	1	2	1	2	2	2	1	2	1	2	1	2	2	2	1	2	1	1	1	1
Fonuakula	1	1	1	2	1	2	1	2	2	2	1	2	1	2	1	2	2	2	1	2	1	1	1	1
Hakupu	1	1	1	2	1	2	1	2	2	2	1	2	1	2	1	2	2	2	1	2	1	1	1	1
Hikutavake	2	2	2	N	2	N	2	N	N	N	2	N	2	N	2	N	N	N	2	N	2	2	2	2
Mutalau	2	2	2	N	2	N	2	N	N	N	2	N	2	N	2	N	N	N	2	N	2	2	2	2
Niufela	2	2	2	N	2	N	2	N	N	N	2	N	2	N	2	N	N	N	2	N	2	2	2	2
Palai	1	1	1	2	1	2	1	2	2	2	1	2	1	2	1	2	2	2	1	2	1	1	1	1
Tafolomahina	2	2	2	N	2	N	2	N	N	N	2	N	2	N	2	N	N	N	2	N	2	2	2	2
Toi	2	2	2	N	2	N	2	N	N	N	2	N	2	N	2	N	N	N	2	N	2	2	2	2
Tumufa	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Vaiea	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Crop suitability ratings for:

Table 17 Root crops

Soil	Cassava	Giant taro	Sweet potato	Taro	Wild yam (Ufilei)	Yam
Avatele	1	2	1	2	2	2
Fetiki	1	2	1	2	2	2
Foa	1	2	1	2	2	2
Fonuakula	1	2	1	2	2	2
Hakupu	2	2	1	2	2	2
Hikutavake	2	2	2	2	2	2
Mutalau	2	2	1	2	2	2
Niufela	2	2	2	2	2	2
Palai	1	2	2	2	2	2
Tafolomahina	2	2	2	2	2	2
Toi	2	2	2	2	2	2
Tumufa	N	N	N	N	N	N
Vaiea	N	N	N	N	N	N

Table 18 Pasture species

Soil	Cylcine wrightii	Mucuna pruriens	Leucaena leucocephala	Siratro atropurepureum
Avatele	2	2	1	2
Fetiki	3	2	2	3
Foa	1	2	1	1
Fonuakula	1	2	1	1
Hakupu	2	3	1	2
Hikutavake	3	3	1	3
Mutalau	3	3	1	3
Niufela	3	3	1	3
Palai	1	2	1	1
Tafolomahina	3	3	1	3
Toi	3	3	1	3
Tumufa	3	N	3	3
Vaiea	3	3	3	3

Table 19 Important plants and commercial tree crops

Soil	Aloe	Jatropha	Makasoi (Cananga odorata)	Nonu	Pandanus	Sugar cane
Avatele	2	1	1	1	1	2
Fetiki	3	2	2	2	2	3
Foa	2	1	1	1	1	2
Fonuakula	2	1	1	1	1	2
Hakupu	2	2	2	2	2	2
Hikutavake	3	3	N	N	N	3
Mutalau	3	3	2	2	2	3
Niufela	3	3	N	N	N	3
Palai	2	1	1	1	1	2
Tafolomahina	N	N	N	N	N	N
Toi	3	3	N	N	N	3
Tumufa	N	N	N	N	N	N
Vaiea	N	N	N	N	N	N

13 Acknowledgements

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14 References and Suggested Further Reading

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Appendix 1 – Abbreviations

Al	Aluminum
AWC	Available water capacity
BS	Base saturation
Ca	Calcium
C	Carbon
$CaCO_3$	Calcium carbonate
CEC	Cation exchange capacity
DM	Dry matter
DSIR	Department of Scientific and Industrial Research
FAO	Food and Agriculture Organization
FC	Field capacity
FCSC	Fertility Capability Soil Classification
Fe	Iron
GIS	Geographic Information System
K	Potassium
Kc	Potassium reserve
Mg	Magnesium
MN	Manganese
N	Nitrogen
Na	Sodium
NZAID	New Zealand Agency for International Development
OM	Organic matter
P	Phosphorus
Si	Silica
SMR	Soil moisture regime

SMU	Soil map unit
SPC	Secretariat of the Pacific Community
STR	Soil temperature regime
S	Sulphur
USDA	United States Department of Agriculture
WP	Wilting point
Z	Zinc

Appendix 2 – Glossary

Base saturation (BS)	May be used as a general measure of soil fertility and leaching. The term *base* refers to those metallic elements that have basic oxides (calcium, magnesium, potassium and sodium). A low BS indicates strong leaching.
Cation exchange capacity (CEC)	This measures the total number of sites in a soil available for cation exchange, and so is a measure of the ability of the soil to retain added nutrients such as calcium, magnesium and potassium. Nearly all the active exchange sites are on the surfaces of clay particles or organic matter (OM). Soils with large amounts of clay or OM usually have a higher CEC than soils low in clay and OM.
Clayey texture group	Soil material with >35% clay. It is very plastic and moderately or very sticky. Includes silty clay, loamy clay and clay.
Drainage	Usually four drainage classes are used: well drained, moderately well drained, imperfectly drained, and poorly drained. The terms indicate how long a soil, or part of a soil is saturated with water, and how quickly it can rid itself of excessive water.
Drought risk	The risk of drought in normal years is expressed as the days of soil moisture deficit and the period (months) when deficits occur.
Erosion hazard	The risk of soil erosion occurring under specified conditions, or in a specified area. Erosion hazard is expressed in qualitative terms (severe, moderate, slight, etc.) and type (e.g. wind).
Field capacity	The moisture content of a soil after it has been saturated and has drained freely.
Horizon	A soil layer that has a texture, colour or other property that distinguishes it from other layers in the soil profile.
Karst	Topography characterised by closed depressions or sink holes in limestone from which surface waters drain by underground routes.
Loamy texture group	Soil material containing 9–35% clay and <40% silt. Includes sandy loam, sandy clay loam, clay loam.
Matching	The process of comparing crop requirements, land qualities and/or soil characteristics to arrive at a land suitability classification.
Matrix	The fine-earth ground mass. (It need not have the dominant colour).
Micro relief	Small-scale local differences in topography, including steps, pits and mounds that are commonly no more than a few metres in diameter and with elevation differences of up to 2 m.

Minimum rooting depth	Soils – in which shallowness, stones, low moisture-holding capacity, low fertility difficult to correct, or salinity are permanent features – are regarded as having limitations in the rooting zone.
Parent material (PM)	The unconsolidated chemically weathered mineral or organic matter from which the slum of soils has developed by pyogenic processes.
Permeability	The quality of a soil horizon that enables water to move through it.
pH	A measure of the acidity or alkalinity of a soil. The pH of a soil is a measure of the acid groups associated with clay or organic matter. Strong leaching or the accumulation of large amounts of organic matter (OM) causes the pH to decrease. pH controls the availability of plant nutrients. The optimum pH level for most plants is about 6.0.
Plateau	Comparatively flat extensive and elevated land area above the adjacent country.
Sandy texture group	Soil material consisting dominantly of sand with 8% or less clay and <40% silt. Includes sand, loamy sand.
Silty texture group	Soil material with 40% or more silt and 35% or less clay. Includes silt loam, loamy silt, and silt.
Soil mapping unit	Any unit describing the spatial distribution of soils, which can be mapped.
Soil profile (slum)	The vertical section of the soil body and although there are exceptions the majority of soil profiles comprise three master horizons (A – topsoil, B – subsoil, and C – parent material). That part that owes its main characters to the soil-forming processes is referred to as the slum. It includes the A and B horizons or the upper part above the parent material horizon.
Soil moisture regime	Soils with an **ustic** moisture regime have limited moisture, but are moist in the season when the soil is suitable for plant growth. In the isohyperthermic STR soils are dry for >90 cumulative days.
Soil series	A group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile; or if genetic horizons are thin or absent, a group of soils that, within defined depth limits, is uniform in all soil characteristics diagnostic for series.
Soil temperature regime	**Isohyperthermic**. The mean annual soil temperature is >22ºC and the difference between summer and winter mean temperature <5 ºC.
Subsoil	The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the surface layer in which roots normally grow.

Topsoil	The original or present dark-coloured surface layers – the A master horizon, consisting of surface mineral horizons with maximum organic accumulation.
Volcanic rocks	These rocks consist of ash and/or magma that has been blown out of a volcano and has cooled and solidified rapidly.
Weathering	The physical and chemical processes in soils that commonly act together. Physical is the breaking of rock into finer and finer particles while the important aspect of chemical weathering is argillisation — the formation of clay. Moisture, temperature, etc., impact the weathering process.

Appendix 3 – Ratings for chemical properties

	Cation-Exchange Properties							Kc
Rating	CEC (me. %)	∑ bases (me. %)	BS (me. %)	Ca (me. %)	Mg (me. %)	K (me. %)	Na (me. %)	(me. %)
Very high	>40	>25	80–100	>20	>6	>1.2	>2	>0.50
High	25–40	15–25	60–80	10–20	3–6	0.8–1.2	0.7–2	0.35–0.50
Medium	12–25	7–15	40–60	5–10	1–3	0.5–0.8	0.3-0.7	0.20-0.35
Low	6–12	3–7	20–40	2–5	0.3–1	0.3–0.5	0.1–0.3	0.10–0.20
Very low	<6	<3	<20	<2	<0.3	<0.3	<0.1	<0.10

Rating	Organic C (%)	Total N (%)	C/N	Adsorbed SO_4 (ppm S)	pH (1:2:5 soil : water)	
Very high	>20	>1.0	>24	>150	>9.0	(extremely alkaline)
High	10–20	0.6–1.0	16–24	50–150	8.4–9.0	(strongly alkaline)
Medium	4–10	0.3–0.6	12–16	15–50	7.6–8.3	(moderately alkaline)
Low	2–4	0.1–0.3	10–12	5–15	7.1–7.5	(slightly alkaline)
Very low	<2	<0.1	<10	<5	6.6–7.0	(near neutral)
					6.0–6.5	(slightly acid)
					5.3–5.9	(moderately acid)
					4.5–5.2	(strongly acid)
					<4.5	(extremely acid)

	Phosphorus (Mg%)			Tamms Extract %		
Rating	P ret %	0.5M H_2SO_4	Total	Al	Fe	Si
Very high	90–100	>40	>120	>3.0	>2.0	
High	60–90	20–40	80–120	1.0–3.0	1.0-2.0	>0.5
Medium	30–60	10–20	40–80	0.5–1.0	0.5–1.0	0.15–0.5
Low	10–30	5–10	20–40	0.2–0.5	0.2–0.5	0.05–0.15
Very low	0–10	<5	<20	<0.2	<0.2	<0.05

Appendix 4 – single factor maps

1. Land cover map of Niue Island (as at 8 September 1994)
2. Depth to cemented coral rock (lithic contact)
3. Surface stones and boulders
4. Surface limestone outcrops
5. Depth to makatea
6. Coarse fragments (coralline stones and/or boulders) in upper 50 cm
7. Potassium (me. %)
8. Topsoil zinc values (ppm)


MAP 2: Land Cover Map Of Niue Island (as at 8th September 1994)
Miscellaneous Map Series
Niue Island
Scale 1: 50 000
Legend
Land Cover Classes | Area ha | Area %
Matured forest 6805.0 26.0
Secondary forest 11232.6 43.0
Littoral forest 1313.0 5.0
Littoral shrubland 455.7 1.7
Managed land 5449.9 20.9
Bare land 886.1 3.4
Main roads
Minor roads
ALOFI
Mutalau
Hikutavake
Toi Valage
Namukulu
Tuapa
Makefu
Lakepa
Liku
Houma
Fonuakula
Tamakautoga
Avatele
Vaiea
Hakupu
HUVALU FOREST
Scale 1: 50 000
Kilometres
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MAP 2: Depth To Cemented Coral Rock (Lithic Contact)
Single Factor Map Series
Niue Island
Scale 1: 50 000
ALOFI
Hikutavake
Namukulu
Tuapa
Makefu
Toi Village
Mutalau
Lakepa
Liku
Hakupu
Avatele
Vaiea
Tamakautoga
Fonuakula
Houma
HUVALU FOREST
Legend
Depth To Cemented Coral Rock
(Lithic Contact)
> 75cm in all pedons
< 75cm in < 50% of pedons
< 75cm in all pedons
Main roads
Minor roads
Acknowledgements
Soil data derived from Leslie, D.M. 1986: Soil Map of Niue Island. Scale 1:50 000. N.Z. Soil Bureau Map 228 and D.M. Leslie 1986, Soil Taxonomic Unit Descriptions (No. 19) for Niue Island 81p.
Topographic base data from Land Information New Zealand (LINZ).
Cartography and GIS operations by T.J. Savage, Landcare Research.
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Map Grid
The grid used on this map is the Niue Map Grid (NGD 1991 - GRS80)
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Scale 1: 50 000
Kilometres
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MAP 3: Surface Stones and Boulders
Single Factor Map Series
Niue Island
Scale 1: 50 000
ALOFI
Mutalau
Hikutavake
Toi Village
Namukulu
Tuapa
Makefu
Lakepa
Liku
Houma
Fonuakula
Tamakautoga
Avatele
Vaiea
Hakupu
HUVALU FOREST
Legend
Surface Stones and Boulders
None or very few (<5% surface cover)
Few stones (5 - 20% surface cover)
Many stones and boulders (20 - 40% surface cover)
Very many to profuse stones and boulders (>40% surface cover)
Main roads
Minor roads
Acknowledgements
Soil data derived from Leslie, D.M. 1986: Soil Map of Niue Island. Scale 1:50 000. N.Z. Soil Bureau Map 228 and D.M. Leslie 1986, Soil Taxonomic Unit Descriptions (No. 19) for Niue Island 81p.
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Kilometres
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MAP 4: Surface Limestone Rock Outcrops
Single Factor Map Series
Niue Island
Scale 1: 50 000
ALOFI
Legend
Surface Limestone Rock Outcrops
None or very few (< 20%)
Many (20 - 50%)
Very many (50 - 80%)
Profuse (> 80%)
Main roads
Minor roads
Acknowledgements
Soil data derived from Leslie, D.M. 1986: Soil Map of Niue Island. Scale 1:50 000, N.Z. Soil Bureau Map 228 and D.M. Leslie 1986, Soil Taxonomic Unit Descriptions (No. 19) for Niue Island 81p.
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MAP 6: Depth To Makatea
Single Factor Map Series
Niue Island
Scale 1: 50 000
ALOFI
Legend
Depth To Makatea
< 75cm to Makatea
> 75cm to Makatea
Main roads
Minor roads
© Landcare Research New Zealand Ltd 2001

MAP 7: Coarse Fragments (Coralline Stones and/or Boulders) In Upper 50cm
Single Factor Map Series
Niue Island
Scale 1: 50 000
ALOFI
Mutalau
Hikutavake
Toi Village
Namukulu
Tuapa
Makefu
Lakepa
Liku
Houma
Fonuakula
Tamakautoga
Avatele
Vaiea
Hakupu
HUVALU FOREST
Legend
Coarse Fragments
(Coralline Stones and/or Boulders)
In Upper 50cm
None or very few stones
(< 5% by volume)
Few to many stones/boulders
(> 5% by volume)
Main roads
Minor roads
Acknowledgements
Soil data derived from Leslie, D.M. 1986: Soil Map of Niue Island. Scale 1:50 000. N.Z. Soil Bureau Map 228 and D.M. Leslie 1986, Soil Taxonomic Unit Descriptions (No. 19) for Niue Island 81p.
Topographic base data from Land Information New Zealand (LINZ).
Cartography and GIS operations by T.J. Savage, Landcare Research.
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Map Grid
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MAP 1: Potassium (me. %)
Single Factor Map Series
Niue Island
Scale 1: 50 000
Hikutavake
Namukulu
Tuapa
Makefu
Toi Village
Mutalau
Lakepa
ALOFI
Houma
Fonuakula
Liku
Tamakautoga
Avatele
Vaiea
Hakupu
Legend
Potassium (me. %)
High (0.8 - 1.2)
Medium (0.5 - 0.8)
Low (0.3 - 0.5)
Very low (< 0.3)
Main roads
Minor roads
Scale 1: 50 000
Kilometres
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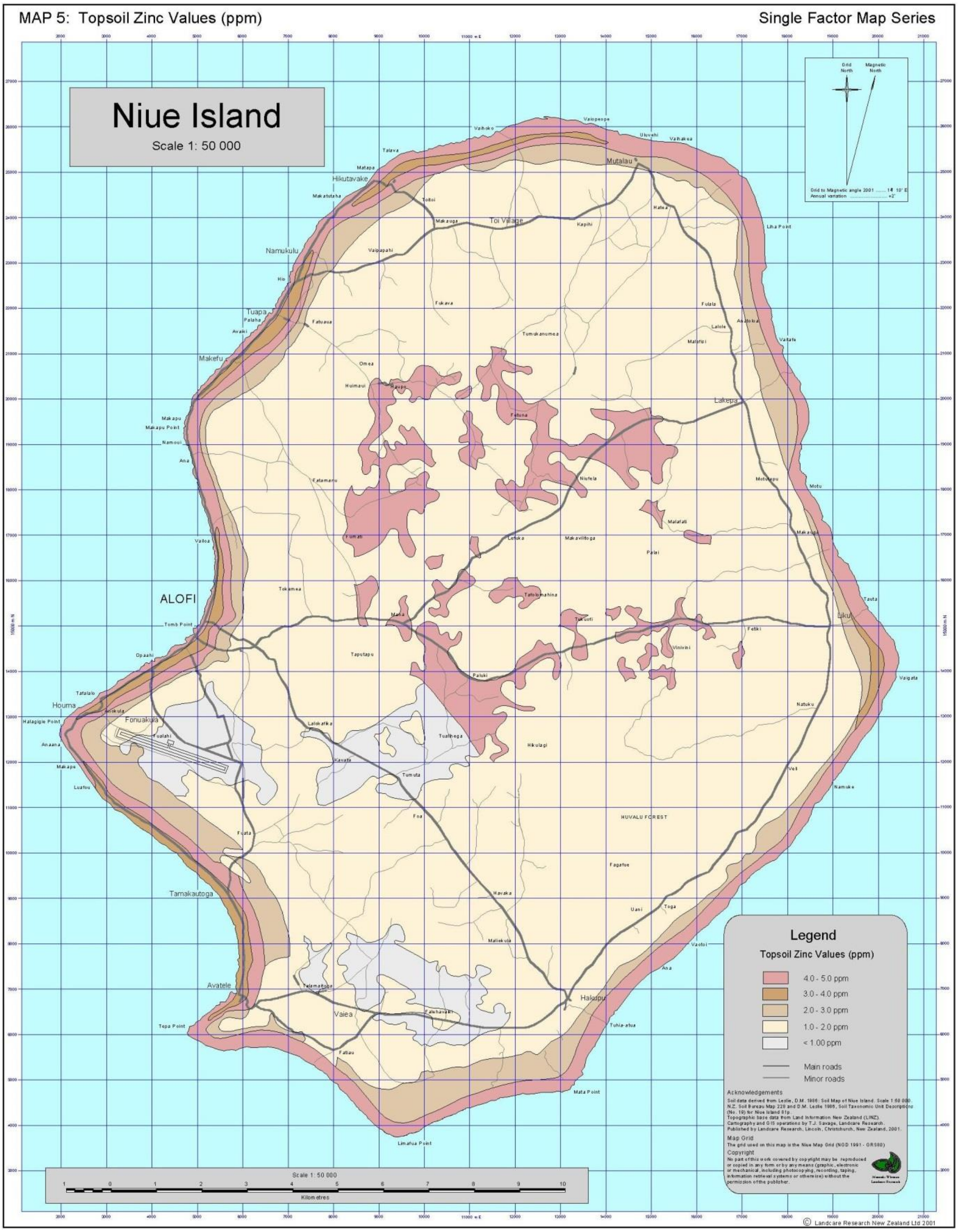
MAP 5: Topsoil Zinc Values (ppm)
Single Factor Map Series
Niue Island
Scale 1: 50 000
Legend
Topsoil Zinc Values (ppm)
4.0 - 5.0 ppm
3.0 - 4.0 ppm
2.0 - 3.0 ppm
1.0 - 2.0 ppm
< 1.00 ppm
Main roads
Minor roads
Acknowledgements
Map Grid
Copyright
ALOFI
Hikutavake
Mutalau
Toi Village
Namukulu
Tuapa
Makefu
Lakepa
Liku
Houma
Fonuakula
Tamakautoga
Avatele
Vaiea
Hakupu
HUVALU FOREST
Scale 1: 50 000
Kilometres
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