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History of soil research conducted by the New Zealand Soil Bureau in five southwest Pacific countries

David M. Leslie

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Contents

Message from the Pacific Community

Information and knowledge sharing on soils is imperative for sustainable soil management, which is fundamental to resilient farming systems in the Pacific Islands. David Leslie's paper, *History of soil research conducted by New Zealand Soil Bureau in five southwest Pacific countries*, is an enormous contribution to the history of soil research and data in the Pacific. Other examples of relevant country-specific publications from David's work include the *Review of Rural Land Use in Fiji* and *Manual for Utilising and Managing Soil Resources of Fiji*.

As a soil expert, David Leslie, who was a team leader for New Zealand soil researchers, conducted research in Pacific countries and is familiar to many soil scientists and agricultural researchers in the region. Having scoured our scattered Pacific Islands to generate comprehensive and invaluable soil data through soil surveys and field experiments, David has imparted much-needed knowledge and skills to novice researchers. This historical soil research and collaboration have strengthened the partnership between the New Zealand Soil Bureau and the Pacific Community (SPC).

SPC has a mandate to support research and development in Pacific Island countries while also working in collaboration with international development partners. For soils, the Land Resources Division (LRD) of SPC has partnered with New Zealand Manaaki Whenua Landcare Research (MWLR) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia to develop the Pacific Soils Portal to enhance soil information and collate new and legacy soil data into more usable forms.

SPC acknowledges and celebrates David's invaluable contributions during the early years of soil research in the Pacific Islands. The publication of this history of soils is the outcome of SPC and MWLR collaboration and will serve as an important reference for future research in the region.

We are confident this publication will make a significant contribution to sustainable land development and management in the Pacific and will serve as an exemplary resource that will benefit regional researchers, soil scientists and agriculturists for many years to come.

Karen Mapusua

Director, Land Resources Division, Pacific Community

Foreword

New Zealand soil and soil-related scientists have had a long and central involvement in soil surveys and soil research in a number of countries in the Pacific Ocean. The first such surveys were an appraisal of soils in Niue and a systematic soil survey in Samoa, both undertaken in 1938.

A Pacific Science Congress held soon after the end of the Second World War recommended that all Pacific Island countries and territories undertake a soil resource survey as a foundation for sound land utilisation. After the survey, Pacific countries began requesting assistance for soil-related work. In 1949, New Zealand (NZ) Soil Bureau staff were sent to Fiji to assist with the UK-funded national soil survey. Another ally in this initiative was New Zealand Aerial Mapping Ltd, which was engaged to do photography in 1951. Many other requests followed, not only from Fiji but also from the Cook Islands, Niue, Samoa and Tonga – all located in the Southwest quadrant of the vast Pacific Ocean and each of which has close ties with New Zealand. New Zealand's involvement broadened and continued, and collaborative efforts expanded to include soil professionals and institutions from other countries.

History of soil research conducted by the New Zealand Soil Bureau in five southwest Pacific countries provides a detailed and important overview of a wide range of soil surveys, research activities and other project initiatives undertaken by NZ in these countries and includes a comprehensive bibliography. This history was painstakingly compiled and written by David Leslie, who was closely involved himself in soil activities in each country as a researcher and later as a leader. Through this work, David became highly familiar with the prevailing circumstances in these small island states. Understandably, capacity in these islands was extremely limited, and having qualified and experienced Soil Bureau officers work alongside local Ministry of Agriculture staff, including agronomists, chemists and also field assistants, was extremely beneficial. David rapidly gained the trust and confidence of these personnel, and they in turn greatly facilitated his work as well as that of other Soil Bureau staff.

This publication lists a host of soil research papers, reports and programs together with manuals, seminars and workshops and expands on the establishment of the South Pacific Agricultural Chemistry (SPACNET) network and the Fiji Soil and Crop Evaluation Project (SCEP) that David conceived. Important collaborating organisations including SPC, USP, ORSTOM, CSIRO, IBSRAM, FARDINAP and the University of Hawaii, and funders such as AusAID, USAID, ADB and the EU are included. In addition, David has included several interesting and often amusing anecdotes – one that stands out is that on his aerial photographic mission in Fiji he sat for 90 minutes in a harness beyond the main door of an RNZAF C-130 Hercules plane!

David's role in the Department of Scientific and Industrial Research (DSIR) in the 1970s included responsibility for soil surveys funded through New Zealand Overseas Development Assistance in Pacific countries, which enabled him to drive and broaden the information generated well beyond soil surveys to extend to crop trials and production budgets, crop suitability assessments, crop market analysis, training, technology transfer and outreach. A key objective was to encourage and facilitate the transfer to, and application of, this knowledge by the land users/owners so that their land resources could be used in a manner that was both economic and sustainable.

David's own research and publication record is outstanding and he set the bar very high in terms of standards and quality. His overall leadership example and innovation and diligence, marked by his own quiet and unassuming style, made a deep impression wherever he worked, and he was held in high esteem by local staff. David has produced this very readable record during his retirement and he deserves strong commendation for his dedicated efforts. It constitutes an invaluable account of the major research contributions made by New Zealand soil scientists in particular to the overall body of knowledge in this important field in the Southwest Pacific. The accumulated soil survey information, together with the research findings and other outputs, in many ways constitutes a legacy for future generations as the region's emerging challenges are addressed, in particular those relating to the impacts of climate change and sea-level rise.

I consider myself fortunate to have worked with David for several of his early years in Fiji and in addition, I have known him for the greater part of his lengthy career.

Robin Yarrow

Permanent Secretary of Agriculture, Fiji, 1979–1983 and 1985–1988

Introduction

The New Zealand (NZ) government has a long history of supporting soil and land resource research in the Pacific, dating back to 1938 when Hamilton and Grange first conducted an investigation of soils in Western Samoa. This support has included funding and technical assistance to Pacific Island countries through soil surveys, soil analysis (chemistry, physics, mineralogy), soil characterisation, soil classification, soil fertility analysis, agronomic studies, soil interpretation for land use, information technology applications of soils data, and training for national and regional staff working in soils and agricultural research.

The majority of projects undertaken by NZ Soil Bureau (now Manaaki Whenua – Landcare Research) were an extension of the New Zealand Overseas Development Assistance programme (NZ ODA), instigated at the request of the participating Pacific Island countries and funded by the Ministry of Foreign Affairs (MFAT) under either bilateral or regional aid programs.

The importance of the soil factor in plant production has long been recognised in Pacific Island countries. Within traditional agricultural systems, variations in soils are frequently reflected by differences in crop production patterns and soil management practices.

Land use is dynamic and responds to economic, social and population pressures. Most Pacific Island countries depend heavily on agriculture for income. Agricultural development within a context of profitability, social desirability, and environmental conservation is a national objective. Such changing needs and pressures focus attention on the necessity for soil resource information. Soil science can provide the soil-related information necessary to help minimise the risks associated with evolving agricultural systems during the initial, and most vulnerable, stages of development. It was within this framework that soil resource studies and soil research were instigated by NZ Soil Bureau, Department of Scientific and Industrial Research (DSIR), in various countries of the Southwest Pacific.

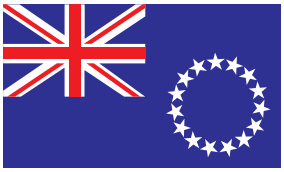
Research by NZ Soil Bureau in the Southwest Pacific was initiated in relation to two main criteria; first, the perceived value of work in helping solve soil related problems in the agriculture, forestry and environment sectors and second, contribution to scientific understanding. The work has been mainly conducted in five southwest Pacific countries – the Cook Islands, Fiji, Niue, Tonga and Samoa – but has also included regional soils projects such as the South Pacific Agricultural Chemistry Laboratory Network (SPACNET), involving nine laboratories in seven countries.

Soil research aims to enhance the living standards and quality of life within the values held by the Pacific Island countries. Soil survey projects describe the nature of soils and their occurrence across the landscape. The soil map therefore acts as a resource document for improving subsistence and cash crop production on a sustainable-yield basis. Other projects have contributed to agricultural development through research into specific aspects of soil fertility and crop production.

A complete bibliography of most of the NZ Soil Bureau research conducted in the Cook Islands, Fiji, Niue, Samoa and Tonga is included in Leslie (2010).[1]

The following chapters provide more detail of the soil research, particularly soil surveys for the Cook Islands, Fiji, Niue and Samoa. Over 200 (Cook Islands, 38; Fiji, 66; Niue, 24; Tonga, 38; Samoa, 9; and regional, 28) reports, maps and research papers have been generated from these soil research programs.

[1] Leslie D.M. 2010. Record of significant soil and land resources research in the South West Pacific. Lincoln, NZ: Manaaki Whenua Press. 52 pp. http://doi.org/10.7931/DL1KS3



1. History of soil research in the Cook Islands

1.1 Soil survey of the Lower Cook Group, Grange and Fox 1953

Early in 1950, the South Pacific Commission suggested to the Department of External Affairs in New Zealand that the Department of Scientific and Industrial Research (DSIR) cooperate in a land utilisation survey of Rarotonga, similar to that in progress in New Caledonia. The proposal was discussed with the Department of Island Territories, and arrangements were made to conduct a soil survey of most islands of the Lower Cook Group.

Les Grange and Pat Fox spent six weeks in July and August 1950 surveying the soils of Rarotonga, Mangaia, Mauke, Atiu, Mitiaro and Aitutaki. This reconnaissance soil survey defined and mapped the six islands of the Lower Cook group, totalling 19,020 ha. While the Grange and Fox bulletin was not complete, it did provide a basis for fertiliser trials, land use surveys, etc.

Maurice Baker and William Hosking Senior accompanied the authors on many of the field days in Rarotonga, and Mane Browne was field assistant during the whole of the survey.

Laboratory analyses were conducted at NZ Soil Bureau laboratories by J. A. Robertson, A. Valk and Graeme Claridge for chemical analyses and clay mineralogy; Les Blakemore and T. W. Collie for phosphate analyses; Morice Fieldes for X-ray and differential thermal analysis; and fusion analyses were carried out by F. T. Seelye (Dominion laboratory). Soils were classified mainly as brown and red lateritic soils derived from basic volcanic rocks. Others were formed from coral sands.

The authors discussed soil genesis and classification with Professor Marlin Cline, Cornell University.[2]

1.2 Transit of Venus, Bruce 1965

In May and June 1965, John Bruce joined four other DSIR officers on the HMNZS *Endeavour* voyage to observe the spectacular solar eclipse on 30 May 1965. The ship visited most islands of the Southern Cook Islands, as well as Palmerston Atoll, Tahiti and Fiji. As time permitted, Bruce examined the soils of the islands visited, described the major soil types, collected soil samples and made observations about land use.[3]

[2] Grange L.I. and Fox J.P. 1953. Soils of the Lower Cook Group. Soil Bureau Bulletin 8. Wellington, NZ: DSIR. 56 pp. https://doi.org/10.7931/4n2x-ay21

[3] Bruce J.G. 1965. Report on Pacific Islands trip. Soil Bureau Information Series No. 14. Wellington, NZ: DSIR. 38 pp.

1.3 Soil survey of Totokoitu Research Station, Leamy et al. 1973

Ian Baumgart, Deputy Director General, DSIR, accompanied New Zealand Prime Minister Norman Kirk on an exploratory visit to several southwest Pacific countries. Resulting from this trip, in 1973, Mike Leamy and Dave Leslie from NZ Soil Bureau visited American Samoa, Samoa, Niue, Tonga, Fiji and the Cook Islands to discuss with their Directors of Agriculture how and in what areas NZ Soil Bureau could assist. It became clear there was demand for more detailed soil mapping and modern soil characterisation with interpretation outlining crop suitability and fertilizer requirements for specific crops and soils. Consequently, Leamy and Leslie undertook a detailed soil survey and assessment at the site of the proposed DSIR Research Station near Titikaveka, Rarotonga. This 135-ha property is located on the south coast and comprises the catchment of the Totokoitu Stream. The terrain is mainly very steep, with 115 ha at an elevation higher than 50 m and the remaining 20 ha comprising flat and sloping land of the narrow coastal plain. The property is typical of the landforms, geology and soils of Rarotonga, and the spectrum of soils occurring on it includes correlatives of most of the soil units recognised by Grange and Fox (1953) throughout the island. The soil pattern is related to the four main landforms: soils of the raised coral beach ridge, soils of the coastal floodplain, soils of the fan remnants, and soils of the hill country and mountainous interior.

FIGURE 1: Dave Leslie and Sir Albert Henry (Premier) at the 1976 opening of Totokoitu Research Station, Rarotonga.

Soil maps were prepared from enlarged air photos on a scale of approximately 1:7920 for the whole property, and approximately 1:2376 for the flat and sloping land of the coastal plain. Soil inspections were based on pits dug on a grid pattern, spaced at approximately 200-m intervals. On the arable portion of the property, 60 profile inspections were made, averaging three per hectare, with fewer observations made on the mountainous terrain. Seven of the nine soil types established by Grange and Fox (1953) were mapped in the survey and three new units were described. Chemical analyses were undertaken by Dean McGaveston and Les Blakemore. Field assistance was provided by Mat Purea.[4]

[4] Leamy M.L., Leslie D.M., Blakemore L.C. and Balbernie B.C. 1975. Soils of the Totokoitu Research Station, Rarotonga, Cook Islands. NZ Soil Survey Report 27. Wellington, NZ: DSIR. 66 pp. http://doi.org/10.7931/DL1-SSR-27

1.4 Soil survey of the Southern Cook Islands, 1974

In 1974, the Cook Islands Soil and Land Use Programme, funded under the NZ Bilateral Aid Programme (Ministry of Foreign Affairs), was initiated in collaboration with the Ministry of Agriculture and Fisheries, Cook Islands. The main objective of the programme was to map and describe soil properties to inform future agricultural development.

Seven soil surveyors from NZ Soil Bureau, DSIR conducted soil surveys of Rarotonga, Aitutaki, Mauke, Atiu, Mitiaro and Mangaia islands. The soil survey teams were assisted during soil sampling by Les Blakemore (soil chemist), Rick Jackson (soil physicist) and John Widdowson (agronomist). Cartography and map production was undertaken by the Science Mapping Unit of DSIR. This was a substantial project with a total staff input of 105 person months (field, laboratory and editing). Bill Sykes, a botanist at DSIR, was seconded to the team and travelled to all of the islands, accompanying the teams on Atiu, Mangaia and Rarotonga. (On his subsequent visits to the Cook Islands, particularly to the Northern Group atolls, he collected further plant material culminating in his magnificent 800-page *Flora of the Cook Islands* published in 2016.)

The NZ Soil Bureau soil surveyors were John Bruce (Soil Correlator for the project), Iain Campbell, Dave Leslie (Team Leader), Trevor Webb, Hugh Wilde and Alasdair Wilson. The islands were mapped by small teams, except for Mitiaro, where Hugh Wilde undertook the survey alone. The team received great support from Barry Balbernie (Food and Agriculture Organization [FAO]), Director of Agriculture and Bill Hosking, Deputy Director of Agriculture. Cook Islands Department of Agriculture staff who provided field assistance included Fred Charlie, Julian Dashwood, David Greig, John Jessie, Marii Mahutariki, Taukea Raui, Ngoro Solomona and David Tuaeu.

For outer island surveys, the team got around on eight specially purchased Yamaha motorbikes, and on Rarotonga, a Department of Agriculture Land Rover was made available. Dave Leslie and Derek Milne travelled to Aitutaki on the final voyage of the *Moana Roa* (principal vessel servicing freight between NZ and the Cook Islands). Transport to the outer islands was on the Silk and Boyd inter-island vessel, *Manuvai*.

The teams were back in Rarotonga for the first week in August 1974 to take part in the weeklong Cook Islands Independence celebrations, which brought many from the outer islands for song and dance competitions and a parade of floats. The recent discovery of "manganese nodules" in Southwest Pacific waters was generating excitement at the time as their commercial recovery might have greatly boosted the local economy.

The soil surveys were contracted to prepare detailed soil maps (scale 1:15,000) of the six islands, sample soils for full physical, chemical and mineralogical characterization, and prepare soil taxonomic unit descriptions (STUDs) for the soil series identified, described and analysed.

Soil samples were collected from type sites for soil chemical, physical and mineralogical analyses and bulk samples for agronomic glasshouse experiments at NZ Soil Bureau laboratories. Sites of detailed profile description (with laboratory numbers) are shown on the soil map.

Derek Milne, assisted by Dave Leslie, carried out the soil survey of Aitutaki. Field mapping and initial soil-map compilation were carried out using vertical aerial photographs enlarged to a scale of 1:8,000. Soil boundaries initially drawn on the 1:8,000-scale photos were later transcribed onto smaller-scale aerial photos and transferred onto the topographic map using standard photogrammetry techniques. Detailed descriptions were made of soils at 52 sites, mainly from pits dug to depths of at least 100 cm. The positions of these sites are shown on the soil map. Partial descriptions were made of soils at a further 83 sites, mainly auger holes, and at a few man-made excavations. Type profiles were classified with varying degrees of certainty according to Soil Taxonomy.

FIGURE 2: Aitutaki soil survey team. Dr Derek Milne with Aitutaki MAF staff.[5]

Iain Campbell, assisted by Alasdair Wilson and Hugh Wilde, carried out the soil survey of Atiu. In the field, 1-m deep soil pits were sited on the different geomorphic surfaces along traverse lines between the centre and outer edge of the island. Auger observations to a depth of 2 m were made from the base of the profile pits. Eighty profile pits were described, and 11 profiles were sampled for analyses. Soil analyses were carried out by Vivienne Vortman and Dean McGaveston. Soil boundaries were drawn on 1:7920 aerial photos and the soil map published at a scale of 1:15,000.[6]

Results of a separate investigation of weathering relationships of the soils mapped during this survey are reported by Campbell et al.[7]

Dave Leslie carried out the soil survey of Rarotonga over three months assisted at different times by Derek Milne, John Bruce and Trevor Webb. Field mapping and initial soil-map compilation were carried out using enlarged vertical aerial photographs at 1:5000 scale. Soil boundaries drawn on these photos were subsequently transcribed onto the 1:10,000-scale topographical map, the final scale of the published map. Detailed descriptions were made of soils from 1-m-deep pits at 98 sites. Partial auger hole descriptions were made at a further 130 sites.[8]

[5] Milne J.D.G. 1991. Soils of Aitutaki, Cook Islands. NZ Soil Survey Report 51. Wellington, NZ: DSIR. 29 pp. http://doi.org/10.7931/DL1-SSR-51

[6] Campbell I.B. 1982. Soils of Atiu, Cook Islands. NZ Soil Survey Report 54. Wellington, NZ: DSIR. 38 pp. http://doi.org/10.7931/DL1-SSR-54

[7] Campbell I.B., Claridge G.G.C. and Blakemore L.C. 1978. Pedological study of soils formed from basaltic parent materials on the Island of Atiu, Cook Islands. New Zealand Journal of Science 21: 229–248.

[8] Leslie D.M. 1980. Soils of Rarotonga, Cook Islands. NZ Soil Survey Report 49. Wellington, NZ: DSIR. 68 pp. http://doi.org/10.7931/DL1-SSR-49

John Bruce and Trevor Webb described and mapped the soils of Mangaia. Field observations and soil boundaries were plotted on aerial photo enlargements at a scale of 1:8000. Soil map data were photo-reduced and the soil map published at a scale of 1:15,000. Bruce established that the topographic map of Mangaia was of incorrect scale and the location of the island was also inaccurate.

Most soils on Mangaia are derived from strongly weathered basalt with a minor influence from limestone weathering products in places. A small area of soils is derived from coral limestone alone. Most soils are very leached, with naturally fertile soils being confined to the most recent alluvial deposits on valley floors. The survey highlighted the very limited area of land suited to intensive cropping (most of which is still unused), the difficulties in developing the most extensive but less fertile soils, and the large area of unproductive steep, hilly land which needs protection from further accelerated erosion.[9]

The soil survey of Mauke was carried out by Alasdair Wilson, Iain Campbell and Hugh Wilde. Field mapping and the initial soil map compilation were carried out using enlarged aerial photographs at a scale of 1:10,000. Soil map data were photo-reduced and the soil map published at 1:15,000.[10]

The soil survey of Mitiaro (carried out by Hugh Wilde) was brief as shipping difficulties limited the time that could be spent there. Detailed work needed to refine the 1:63,360 reconnaissance soil map of Mitiaro (Grange and Fox 1953) could not be carried out. Only a few areas on the island were visited and examination of the soils was limited to one ground traverse, but these limited observations allowed some detailed soil descriptions. Fortunately, high quality aerial photographs were available (scale 1:31,000) and interpretation of them allowed soil boundaries to be plotted more accurately than on the previous reconnaissance map.[11]

Soil samples from the surveys underwent laboratory analyses and glasshouse fertility experiments at the NZ Soil Bureau laboratory in Taita, NZ. These investigations commenced in 1974. Soil chemical analyses were carried out by Vivienne Vortman, C.P. Fredricsen and Dean McGaveston. Soil water retention analysis was done by Maurice Gradwell and particle size by Fletcher Thomas.

Chemical analyses used standard soil methods (Blakemore et al. 1972). The glasshouse experiments assessed plant nutrient status of 20 representative Southern Cook Island soils. Green Panic, *Panicum maximum* var. *trichoglume*, was used to examine plant response to major soil nutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium) and minor nutrients (molybdenum, boron, copper, zinc and manganese) using a subtractive technique. Green panic was grown for four months under glasshouse conditions, simulating the climate of the Cook Islands. The grass was harvested four times, at three-week intervals and at a cutting height 10 cm above the soil surface.[12]

In 1979, NZ Soil Bureau staff involved in the 1974 soil surveys of the Southern Cook Islands Group contributed to a non-technical booklet about the soils of the Cook Islands, compiled and coordinated by Bernard Healy. The booklet was written primarily for use in schools to provide students with wider understanding of their country's soil resources.[13]

[9] Webb T.H. 1980. Soils of Mangaia, Cook Islands. NZ Soil Survey Report 50. Wellington, NZ: DSIR. 52 pp. http://doi.org/10.7931/DL1-SSR-50

[10] Wilson A.D. 1982. Soils of Mauke, Cook Islands. NZ Soil Survey Report 52. Wellington, NZ: DSIR. 59 pp. http://doi.org/10.7931/DL1-SSR-52

[11] Wilde R.H. 1981. Soils of Mitiaro, Cook Islands. NZ Soil Survey Report 53. Wellington, NZ: DSIR. 20 pp. http://doi.org/10.7931/DL1-SSR-53

[12] Widdowson J.P. and Blakemore L.C. 1975. Fertility of Cook Islands Soils. Interim Reports: 1. Glasshouse Studies; 2. Soil Analyses. NZ Soil Bureau. Wellington, NZ: DSIR. 46 pp.

[13] Soil Bureau Staff 1979. Soils of the Cook Islands – An Introduction. Wellington, NZ: Ministry of Foreign Affairs. 44 pp.

1.5 The Cook Islands Soil and Land Use Programme

The Cook Islands Soil and Land Use Programme seminar was held in Rarotonga on 21–25 July 1975 for NZ Soil Bureau scientists to report soil survey and fertility trial results to their associates in the Cook Islands and to determine the final design of reports, field trials, and the soil moisture programme. The seminar was opened by Premier Sir Albert Henry, with Jim Little, the NZ Deputy High Commissioner, in attendance. The NZ Soil Bureau presentation team included Les Blakemore, John Bruce, Dave Leslie, Derek Milne and John Widdowson. This highly successful seminar generated useful discussion about the final design of reports, information booklets, field trials, and the soil moisture programme.[14]

Field fertiliser experiments (using maize) were implemented by John Widdowson and Lionel Hume to validate results from the glasshouse experiments. Trials were also established to advise on formulation and quantities of fertiliser required for the banana and citrus industries.

A hydraulic properties programme was also established to measure selected soils on Aitutaki and Rarotonga to better understand soil moisture relationships under citrus, banana and coconut and to monitor citrus blocks at Totokoitu Research Station to provide irrigation schedules for citrus.[15,16,17,18,19]

[14] Soil Bureau Staff 1975. Cook Islands Soil and Land Use Programme: Report on Seminar July 21–25 1975. Soil Bureau. Wellington, NZ: DSIR. 40 pp.

[15] Hume L.J., Healy W.B., Hosking W.J., Manarangi A. and Tama K. 1985. NPK fertiliser rates for citrus on Rarotonga, Cook Islands. NZ Soil Bureau Scientific Report 75. Wellington, NZ: DSIR. 17 pp. http://doi.org/10.7931/DL1-SBSR-75

[16] Hume L.J., Healy W.B., Tama K., Hosking W.J., Manarangi A. and Reynolds J. 1985a. Responses of citrus (*citrus sinensis*) to NPK fertiliser of two soils on Rarotonga, Cook Islands 1. Effects of NPK fertiliser rate on soil properties and leaf nutrient levels. New Zealand Journal of Agricultural Research 28: 475–486. https://doi.org/10.1080/00288233.1985.10417993

[17] Hume L.J., Healy W.B., Tama K., Hosking W.J., Manarangi A. and Reynolds J. 1985b. Responses of citrus (*citrus sinensis*) to NPK fertiliser of two soils on Rarotonga, Cook Islands 2. Effects of NPK fertiliser rate, soil properties, and leaf nutrient levels on yield and tree size. New Zealand Journal of Agricultural Research 28: 487–495. https://doi.org/10.1080/00288233.1985.10417994

[18] Hume L.J. and Widdowson J.P. 1986. Response of sweetcorn to lime on an Ultisol from Atiu, Cook Islands. New Zealand Journal of Agricultural Research 29: 269–273. https://doi.org/10.1080/00288233.1986.10426982

[19] Hume L.J., Widdowson J.P., Hosking W.J. and Tama K. 1979. Responses to fertiliser NPK and S by maize on three soils of Rarotonga, Cook Islands. New Zealand Journal of Experimental Agriculture 7: 235–243.

1.6 Soil Moisture Programme, 1975–1977

In 1975, a soil water measurement project was implemented by Rick Jackson (funded by NZ Overseas Development Assistance) to investigate water relations of important agricultural soils in Aitutaki and Rarotonga as water availability was potentially limiting intensive crop production on these soils. Information on soil water regimes was also expected to assist in understanding the genesis and classification of the soils.

The objectives were: 1) to determine the water storage characteristics of key soils; 2) to determine to what extent and to what depth the water storage capacity of the soil was exploited by tree crops; and 3) to determine how well the measured changes of water content could be simulated using simple weather records and a water balance model. If the water balance model appeared satisfactory, long-term weather records would be used to assess the probability of soil-water deficits at the sites where rainfall data was available.

Repeated measurements of soil water status were the main part of the project and of the various techniques available (gravimetric sampling, tensiometers, resistance blocks and neutron probe), only the neutron probe seemed suitable for use at sites on Aitutaki and Rarotonga.

Rick Jackson, assisted by Dave Leslie, installed the probe access tubes. Installation included core sampling at close intervals down the entire depth of the installation. These core samples were to measure water content, bulk density, particle density and water retention at 15 bar pressure potential (wilting point) to provide initial characterisation of the soils and check calibration of the neutron probe. Fred Charlie, Department of Agriculture, Aitutaki, took over the operation and maintenance of the neutron probe, taking water content measurements at Aitutaki and Rarotonga sites at two-week intervals.

Five soils (Matavera, Muri, Pouara, Nikao and Arorangi) were chosen to represent the more important agricultural soils of Rarotonga. Each of the sites was on a citrus block. The Tautu soil series was chosen to represent the most important soil on Aitutaki.

FIGURE 3: Neutron probe installation during Soil Moisture Project, Aitutaki (1976). Dr Rick Jackson, Fred Charlie, MAF support, John Jessie.

1.7 Mitiaro peat survey, Wilde 1988

In June 1988, on a contract to the South Pacific Regional Environmental Programme, Hugh Wilde evaluated the volume of peat occurring on Mitiaro and its suitability for use as an energy fuel or for agricultural uses as a soil conditioner, a nursery medium for seed raising or as an organic supplement in ornamental gardens.

The island comprises a raised coral limestone reef encircling a central depression (total area 420 ha) occupied by brackish swamp and lakes, which contain four small basaltic islands or food lands (120 ha).

Fieldwork consisted of examining and describing lakeside and swamp sediments (peat, rotted vegetation, algae or coral sand) across swamp traverses approximately every 30 m, sampling with a 2.2-m-long auger. Walking the traverse was only possible on the higher parts of the lake margin and throughout the swamp where sedge-dominated vegetation occurred or where the bottom sediments comprised firm coral sands. Elsewhere, wading and swimming was necessary!

Samples were collected for laboratory analysis of pH, organic matter content, cation exchange capacity (CEC), exchangeable bases, soluble salts, calcium carbonate content, and major and minor elements. Chemical analyses were carried out by Janice Willoughby and Matthew Taylor. John Hunt used X-ray fluorescence (XRF) to conduct major and trace element analyses.

Hugh calculated the volume of peat on Mitiaro as 59,000 m^3, with a wet weight of 59,000 t or dry weight of 3700 t. Loss on ignition and organic carbon contents indicated that the lake margin peat was wholly composed of organic materials (> 80%), whereas peat samples collected from the swamp contained much less organic matter (< 60%).

A report on peat deposits of Mitiaro included an estimate by the Ecology Division, DSIR of the environmental impact of peat mining, including the effect on aquatic life in the two lakes.[20]

1.8 Soil Classification Project, Bruce 1983

In 1982, John Bruce, soil correlator for the soil surveys of the Southern Cook Islands Group, described the soil patterns and classification according to Soil Taxonomy. Six soil orders were recognised: Oxisols, Ultisols, Mollisols, Alfisols, Inceptisols and Entisols, which were further subdivided into 12 suborders, 15 great groups and 25 sub-groups. Oxisols occur only on Mangaia; Ultisols occur on three of the four Makatea islands (Mangaia, Atiu and Mauke) as well as Aitutaki; Mollisols occur on all six islands, although on the four Makatea islands (including Mitiaro), they generally have a shallow lithic contact with the underlying limestone; Inceptisols occur on five of the six islands (the exception being Mitiaro); and Entisols are represented on all six islands. The older, more weathered soils (Oxisols and Ultisols) occur on remnant surfaces and grade with either decreasing altitude or age of land surface to Alfisols, Mollisols, Inceptisols and Entisols, respectively.[21]

[20] Wilde R.H. 1988. Peat deposits of Mitiaro, Southern Cook Islands. NZ Soil Bureau Contract Report 88/17. Wellington, NZ: DSIR. 33 pp.

[21] Bruce J.G. 1983. Patterns and classification according to Soil Taxonomy of the soils of the Southern Cook Islands. Geoderma 31. 301–323. https://doi.org/10.1016/0016-7061(83)90043-5

1.9 Atiu Land Use Capability Project, 1990

In 1990, DSIR Land Resources conducted a land use capability (LUC) project on Atiu Island under the NZ Overseas Development Assistance programme to develop a land use capability method from which Cook Island government officers (Lands & Survey Department, Department of Agriculture, Ministry of Works and Department of Conservation) could retrieve information relevant to sustainable land use. The LUC survey team comprised Murray Jessen (Team Leader), Mike Page, Hugh Wilde and Don Miller.

The LUC survey was based on detailed fieldwork, coupled with stereoscopic interpretation of 1:10,000-scale vertical colour aerial photographs. Data was plotted onto a large orthophoto of Atiu and later transferred to a digital database using a geographic information system (GIS). The database was managed by the Survey Department, Rarotonga. Hugh Wilde described and sampled soils for laboratory analysis and his results form an appendix to the report.[22]

Don Miller identified and documented erosion problems on Atiu and designed appropriate soil erosion control techniques to minimise soil losses. This manual was prepared for use by the Cook Islands LUC team and by interpreters of the database.[23]

The LUC units defined for Atiu indicated the general limitations of land for agricultural use. The units grouped together areas of land which respond similarly to the same management, are adapted to the same kinds of crops, have similar potential yield, and require the same conservation measures. While LUC units may be adapted to a certain range or grouping of crops, they do not indicate suitability for specific crop requirements as different crops have different environmental requirements.

Bruce Trangmar joined the project to match crop requirements with land characteristics, management requirements and indicative suitability ratings for specific crops determined for each LUC unit. Trangmar's report described the methods used to determine the crop suitability ratings, tabulated and discussed the derived ratings for each LUC unit for each specific crop, and identified the key environmental factors influencing each rating. Crop suitability ratings were determined for each LUC unit for the following crops:

- Root crops (kava, taro, ginger, sweet potato, yam, cassava)
- Vegetables (Chinese cabbage, lettuce, cucumber, tomato, melon)
- Tree crops (Robusta coffee, guava, coconut, avocado, papaya, mango, macadamia, citrus, banana)
- Other (pineapple, cowpea, climbing bean, black pepper, vanilla)

A four-class rating system was applied to assess the general effect of each environmental factor on crop growth and management.[24]

[22] Jessen M.R., Page M.J., Wilde H.R. and Miller D.E.K. 1990. Land Use Capability of Atiu, Cook Islands – Survey Report and Mappers Handbook. DSIR Land Resources Contract Report 90/15. Wellington, NZ: DSIR. 119 pp.

[23] Miller D.E.K. 1990. Erosion Control Handbook, Atiu, Cook Islands. DSIR Land Resources Contract Report 90/16. Wellington, NZ: DSIR. 55 pp.

[24] Trangmar B.B. and Jessen M.R. 1990. Crop suitability ratings, Atiu, Cook Islands. DSIR Land Resources Contract Report 90/23. Wellington, NZ: DSIR. 23 pp.

1.10 GIS Development Project, 1993–1998

The Cook Islands GIS Development Project, which operated for six years (1993–1998), was a NZ Ministry of Foreign Affairs and Trade (MFAT) management services contract awarded to ANZDEC Ltd with technical input provided by Landcare Research, NZ. The aim of the project was to assist the Cook Islands government in establishing an integrated GIS facility in four government departments (Lands & Survey Department, Ministry of Works, Department of Agriculture and Department of Conservation). This was to enable improved access to and management of spatial natural resource information, particularly soils, required for departmental decision-making in operations and planning.

Roland van Asch, ANZDEC, was Project Director; Dave Leslie, Technical Coordinator/Training Adviser; David Giltrap, GIS/Database Specialist; and James Barringer, GIS/Remote Sensing Specialist. GIS training was conducted in New Zealand at Landcare Research by Robert Gibb, Peter Stephens, John Dymond and Bruce Trangmar. Giltrap developed specifications for the GIS and oversaw the installation and commissioning of GIS computer hardware and software in four government departments.

The project conducted the following training courses in addition to one-on-one 'hands-on' GIS and database training when consultants were in-country: 1) an initial three-month GIS course for six trainees (Timoti Tangiruaine, Lynley Andrew, Patrick Arioka, Cecelia Haupini, Benjamin Classie and George Taikakora) in New Zealand; 2) a four-week secondment for a GIS-trained operator; 3) a two-week GIS course in Rarotonga for 22 trainees; 4) a two-week Paradox course for 10 trainees; and 5) a three-week GIS training course for eight trainees.

David Giltrap and James Barringer oversaw the digital capture (digitizing and scanning) of data which included cadastre, land valuation, soils, land use, topography, hydrology, infrastructure, service utilities and cultural data for the Cook Islands.

Practical advice was provided on hardware/software maintenance/upgrades and servicing. Dave Leslie assisted the Cook Islands government establish an interdepartmental steering committee, a Technical Operating Group (TOG) comprising the 'hands-on' GIS operators, and a less formal Users Forum (all heads of departments and appropriate state-owned enterprises).

The Cook Islands project management counterparts were Oliver Peyroux, Surveyor-General and Nga Mataio, Director of Agriculture.

1.11 Cook Islands Land Use Policy and Rarotonga Land Zoning Project, 2008

The Secretariat of the Pacific Community (SPC) contracted Dave Leslie in 2008 to prepare a draft Land Use Policy for the Cook Islands. The draft is still being considered by the Cook Islands government.[25]

Due to urban expansion onto soils of high value for horticulture on Rarotonga and onto hill slopes involving poorly constructed roading and substandard site preparation, there was a request from the Cook Islands government for a Draft Land Zoning Plan. Based on the soil map, Dave Leslie, with GIS input by James Barringer, prepared a zoning plan with definitions for each of the zoning units on the map. SPC provided funds for *vaka* (community) meetings around Rarotonga to seek agreement on the plan and definitions. The term 'land husbandry' replaced 'zoning' in response to public opinion in Rarotonga.[26,27]

[25] Leslie D.M. 2008a. Draft Land Use Policy for the Cook Islands. Secretariat of the Pacific Community. Noumea, New Caledonia: SPC. 21 pp.

[26] Leslie D.M. 2008b. Land Husbandry Unit Definitions for Rarotonga. Secretariat of the Pacific Community. Noumea, New Caledonia: SPC. 14 pp.

[27] Leslie D.M. and Barringer J.R.F. 2008. Draft Land Zoning Plan. Secretariat of the Pacific Community. Noumea, New Caledonia: SPC.

1.12 Soil Resources Information Manual, 2012

In 2011, Dave Leslie was contracted by FAO to prepare a soil resources manual for the Southern Cook Islands Group. The manual collates all available information about soil fertility, crop options, farming systems and soil management:

- Physiographic soil legends where soil mapping units are hierarchically organized according to temperature regime, landscape type, composition and degree of weathering of parent material and, finally, drainage class
- Classification of soil series according to Soil Taxonomy and the FAO/UNESCO system
- Keys to the identification of soil series; the flow-diagram format is also in hierarchical order for the physiographic soil legends
- Land and soil attributes significant for crop growth are presented in spreadsheet format for each soil mapping unit
- Soil use classifications
- Land and soil constraints for crop growth
- Soil fertility of Southern Cook Islands Group soils
- Fertility capability soil classification of soil mapping units
- Chemical characteristics of soils
- Land qualities of soil mapping units matched with individual crop requirements and expressed in one of four classes of crop suitability
- Soil and land management

The soil and land use information in the manual was derived from comprehensive technical reports (Leslie 1980; Webb 1980; Milne 1981; Wilde 1981; Campbell 1982; Wilson 1982; Bruce 1983) written for the detailed soil surveys of the Southern Cook Islands Group in 1974, and the results of laboratory analyses and glasshouse pot experiments.

Based on the crop suitability analysis, GIS was employed to generate 43 single-factor maps. The GIS work was undertaken by Timoti Tangiruaine, Ministry of Infrastructure and Planning, Rarotonga.

Dave Leslie provided crop gross margin budgets for the 43 crops that can be regularly updated for production, commodity and labour costs. William Wigmore, Head of Extension and Research, Ministry of Agriculture and Fisheries, Cook Islands provided significant technical assistance throughout the project.[28]

[28] Leslie D.M. 2012. An Information Manual for Understanding and Managing the Soil Resources of the Southern Cook Island Group. FAO Field Publication. Rome, Italy: FAO. 117 pp.

2. History of soil research in Fiji

2.1 Reconnaissance soil survey of Fiji, Twyford and Wright

A memorandum for an agricultural policy for Fiji was adopted by the Legislative Council in February 1946, and the principle that a soil reconnaissance of Fiji was fundamental for any comprehensive programme of agricultural development was accepted. The soil chemist that had been undertaking local soil surveys left Fiji in 1949, and the project was deferred due to lack of staff.

In 1949, the Government of Fiji sought assistance from the New Zealand government and the Department of Scientific and Industrial Research (DSIR) for a reconnaissance soil survey of Fiji – in line with a Pacific Science Congress recommendation that all Pacific Island countries and territories have a soil survey as a sound basis for proper land utilisation as well as information on crop yields and fertiliser trials etc. obtained for crops that could be related to soil types. In response, Les Grange was seconded from the New Zealand (NZ) Soil Bureau to the Fiji Department of Agriculture, and Charles Wright visited the Department of Lands, Mines and Survey, Suva, to obtain a complete set of geological maps for Fiji.

In July 1949, Les Grange visited Fiji for a month to discuss the details of a projected soil survey of the Fiji group. Grange prepared a report to the Colonial Secretary, Suva describing the methodology for the soil survey and a budget (GBP 1900 for the reconnaissance survey and GBP 800 for a detailed survey of the lowlands) with an annex describing soils and erosion issues. The proposal was for a reconnaissance survey mapping on a scale of 1 mile to 1 inch, which was reduced to 3 miles to 1 inch for the final report. For Viti Levu and Vanua Levu, conducting detailed surveys of alluvial soils at a scale of 16 chains to an inch and reduced to 40 chains to an inch would occupy up to six months. Grange also described and sampled 15 soils from the Koronivia and Sigatoka agricultural research stations for analysis (conducted by N.C. Ashman).

Topographical maps and aerial photo coverage were also required. Topographical map coverage at a scale of 1:63,630 was available for Fiji, but aerial photo coverage was limited. New Zealand Aerial Mapping Limited had flown the Rewa delta and Lautoka and environs during the Second World War, and further flights were discussed with Piet Van Ash of New Zealand Aerial Mapping, who supplied a quote in 1954 for aerial mapping of Fiji at GBP 3.50 per square mile of the main islands for supplying two sets of prints at a scale of 20 chains to 1 inch.

In 1950, the Fiji Legislative Council approved the soil survey of Fiji, which was funded by the United Kingdom Colonial Development Fund, with the New Zealand government supplying personnel and materials to assist the survey. New Zealand Aerial Mapping Ltd were engaged to undertake aerial photography of Fiji in 1951. Ian Twyford was appointed as a soil survey chemist to undertake laboratory studies at NZ Soil Bureau in collaboration with the field survey team. In 1952, Pat Fox and Ian Baumgart commenced the more detailed reconnaissance survey of Fiji (following on from Grange 1949) for which they were paid a daily allowance of 30 shillings. By 1953, the main lowland agricultural areas of Viti Levu had been mapped. Owing to the shortage of Soil Bureau staff, only limited fieldwork was done in 1954, chiefly on the Nadrau Plateau and windward Taveuni Island by Twyford. In 1955, Charles Wright joined the team and mapped the soils of Vanua Levu and some adjacent islands, assisted for part of the time by Mike Leamy. Leamy developed appendicitis and despite Wright's offer to operate with a sharp pocketknife and a bottle of whiskey, Leamy flew back to Auckland for the operation. In 1956, work was again interrupted as Wright was engaged with the soil survey in Samoa and the Chatham Islands, but in 1957, Kadavu, Taveuni and the interior of Viti Levu were mapped with the assistance of Valuma Tora (later, Head of Land Use Section, Ministry of Primary Industries [MPI], Fiji). In 1958, the remaining islands of the Lomaiviti, Lau and Yasawa groups were mapped by Twyford and Tora. Savenaca Dolo and Satendra Singh carried out the laboratory work at Koronivia Research Station.

The comprehensive two-volume bulletin, *The Soil Resources of the Fiji Islands*, was produced by Ian Twyford and Charles Wright in 1959 as the result of intensive fieldwork with accompanying laboratory studies and a detailed inventory of land use in Fiji in the 1950s. Francis Tindall, divisional draughtsman at NZ Soil Bureau, was responsible for the overall production of the figures and maps. Chapters cover:

- The natural environment of Fiji and factors determining the soil pattern
- The general soil pattern and the basis of the soil classification
- A general description of the properties of the main soil sets and their fertility as determined by analysis, pot trials and field experiments
- How data were combined to produce land classification maps and estimates of potential land use
- An account of the history of land use
- The soil pattern and land use potential of each of the main islands as well as most of the outer islands

Volume 2 includes:

- Eight soil map sheets at a scale of 1:126,720
- Eight land classification sheets with legend
- Soil map legend
- General soil pattern map
- Generalised land use map
- Geological map
- Rainfall and climate map
- Map of alienated land in Fiji
- Land slope map
- Population distribution map

The soil survey established 55 soil sets with 217 soil types. Soils were separated into lowlands and upland and further subdivided based on rainfall distribution, labelled as: no, weak, moderate and strong dry seasons. The soil classification developed by Wright was unique to Fiji but was influenced by the development of the United States system. Wright found soils with the weakest zonal impress were recent soils from the coastal sands and river alluvia. Soils with high water tables, gley soils, showed only a weak to moderate zonal impress. Two other major groups of soils displaying only a weak or moderate degree of zonal impress were the black soils derived from base rich parent materials and those soils derived from recent volcanic materials. The remaining Fiji soils strongly reflect the impress of the local environment. In classifying soils according to their ability to record the zonal impress, full expression was given to the acquired characteristics in soil formation. The principle broad units of classification were: recent soils from coastal sands; recent soils from river alluvium; nigrescent soils; latosolic soils; humic latosols; ferruginous latosols; red-yellow podsolic soils; gley soils; steepland soils; and organic soils.[29]

[29] Twyford I.T. and Wright A.C.S. 1965. The Soil Resources of the Fiji Islands. Two volumes. Government of Fiji, Suva. 570 pp. (23 maps are available from https://nla.gov.au/nla.obj-543874596/view)

2.2 Lau Group, 1977

Following the success of the Royal Society of NZ expedition to the Cook Islands and Tonga in 1969 to celebrate the Cook bicentenary, NZ Ministry of Foreign Affairs (MFA) funded a 1977 expedition to Lau Group and Tonga with 14 DSIR staff and scientists from NZ universities. The Royal Society of NZ published 12 papers from the expedition in a bulletin in 1978.

As part of this expedition, Dave Leslie and a small team flew to Lakeba Island in Lau Group, where the Chief Roko, Ratu Tevita Uluilakeba, provided great assistance with transport and field assistance for the soil survey.

Soils previously mapped in earlier surveys (Twyford and Wright, and Overseas Scientific and Technical Research Office [ORSTOM], France) were re-examined and classified according to Soil Taxonomy. The soil pattern is almost wholly explainable by the island's dissection and erosion history. On hill slopes, Oxisols (Haplorthox, Eustrustox, Acrustox) occur on stable sites, while on unstable sites that have experienced continued erosion, Inceptisols develop. Depending on the surface age, Ultisols and Alfisols occur in the alluvial valleys on older alluvium and Mollisols developed in areas of more recent alluvial deposits.

Soil analyses were undertaken at NZ Soil Bureau by Adrienne Hall, Jane McCarten, Christine Gwilliam, Dean McGaveston and Joe Whitton.[30]

For Lakeba, the objectives of the soil survey of Vanua Balavu were to examine and describe the principle taxonomic units occurring within soil units established by Twyford and Wright, undertake selected traverses across the landscape to ascertain the variability within the mapping units, and classify selected profiles according to Soil Taxonomy. A map at a scale of 1:25,000 was produced. Twenty pedons were sampled for laboratory analysis at NZ Soil Bureau. The soils classified as a Haplustox, a Chromustert, two Rhodustults, a Haplaquoll, three Haplustolls, a Haplustalf, three Ustropepts and two Ustorthents. Setareki Koto was field assistant on Vanua Balavu.

The northern part of the island is raised coral limestone with a rugged surface and no roads. Dave Leslie and his team visited the area in a long punt with an outboard motor that failed 10 km from home. Unable to restart the motor, they drifted within the wide lagoon throughout the night, getting perilously close to the reef, but fortunately the tide changed and took them back toward land. They were found after dawn by two islanders out fishing and towed back to the island. At the end of the survey, the team were picked up by the DSIR oceanographic vessel RV *Tangaroa* and sailed overnight to Suva.[31]

[30] Leslie D.M. and Blakemore L.C. 1978. Properties and classification of the soils of Lakeba, Lau group, Fiji, in Lau-Tonga, 1977. Bulletin, The Royal Society of New Zealand 17: 164–190.

[31] Leslie D.M. and Blakemore L.C. 1985. Properties and classification of selected soils from Vanua Balavu, Lau Group, Fiji. Journal of the Royal Society of New Zealand 3:313–327. https://doi.org/10.1080/03036758.1985.10416835

2.3 Soil surveys of Fiji Agriculture Research Stations, 1980–1982

Under the Bilateral Aid Programme with Fiji, the NZ Ministry of Foreign Affairs (MFA) funded soil surveys of Fiji Agricultural Research Stations (ARS) at Dobuilevu, Koronivia, Legalega, Naduruloulou, Nawaicoba, Waidradra and Sigatoka on Viti Levu, and Seaqaqa and Wainigata on Vanua Levu, plus Tutu and Vunilagi Estates and Rotuma Island.

The soil surveys were conducted in 1980–1982 by eight pedologists from NZ Soil Bureau, DSIR – Michael Laffan, Dave Leslie (Team Leader/Soil Correlator), Malcolm McLeod, Robin Palmer, Brian Purdie, Wim Rijkse, Graham Shepherd and Steve Smith – and one from Massey University, Vince Neall. In 1980, after the first survey (Koronivia ARS) was completed, Mike Leamy and Les Blakemore visited to finalise analytical arrangements at Koronivia laboratory and the logistics for the remaining surveys. The total input for the project was 40 person months.

The soil survey teams for each of the research stations were as follows: Koronivia: Dave Leslie; Legalega: Michael Laffan and Leslie; Nawaicoba: Leslie and Laffan; Seaqaqa: Brian Purdie, Laffan and Graham Shepherd; Waidradra: Steve Smith and Robin Palmer; Dobuilevu: Malcolm McLeod and Wim Rijkse; Naduruloulou: Palmer and Smith; Sigatoka: Rijkse and McLeod; Tutu Estate: Shepherd and Vince Neall; Vunilagi Estate: Shepherd and Neall; and Rotuma Island: Laffan and Smith.

FIGURE 4: Georgina Finau, Wim Rijkse, Malcolm McLeod, Vilitati Seru and Graham Shepherd discussing the soil survey of Sigatoka Research Station.

Surveys were detailed at scales of 1:1,500 (ARS), 1:3,000 (Tutu and Vunilagi Estates) and 1:25,000 (Rotuma Island). Soil survey reports were written for nine stations with maps and soil taxonomic unit descriptions (STUDs), with only STUDs prepared for Wainigata and Vunilagi Estates.

Soil chemical analyses were carried out at both Koronivia Research Station, Fiji (by Jone Korovou, William Magnus, Bardu Singh and Iliseva Ratunivatulele) and NZ Soil Bureau Taita laboratory (by Ruth Langham, Keitha Giddens, Noel Kendall, Brian Daly and Matthew Taylor), where soil physical analyses (John Claydon) and mineralogy (Joe Whitton) required for soil classification were also carried out. Some of the Tutu Estate analyses were carried out at Massey University, New Zealand (S. Martin and S. Zambasos).

Fostino Kafoa, Head of the Land Use Section, MPI, Fiji, provided excellent support throughout the project and being a Rotuman, accompanied Michael Laffan and Steve Smith on the survey of that island. Kafoa also made Vilitati Seru available to accompany the survey teams mapping on Viti Levu and Vanua Levu.[32,33,34,35,36,37,38,39,40,41,42,43]

[32] Laffan M.D. 1988a. Soils of Legalega Agricultural Research Station, Viti Levu, Fiji. NZ Soil Survey Report 77. Wellington, NZ: DSIR. 28 pp. http://doi.org/10.7931/DL1-SSR-77

[33] Laffan M.D. 1988b. Soils of Seaqaqa Agricultural Research Station, Vanua Levu, Fiji. NZ Soil Survey Report 79. Wellington, NZ: DSIR. 29 pp. http://doi.org/10.7931/DL1-SSR-79

[34] Laffan M.D. and Smith S.M. 1986. Soils of Rotuma, Fiji. NZ Soil Bureau Report 72. Wellington, NZ: DSIR. 38 pp. http://doi.org/10.7931/DL1-SSR-72

[35] Leslie D.M. 1984a. Soils of Koronivia Agricultural Research Station, Viti Levu, Fiji. NZ Soil Survey Report 75. Wellington, NZ: DSIR. 46 pp. http://doi.org/10.7931/DL1-SSR-75

[36] Leslie D.M. 1984b. Soils of Nawaicoba Agricultural Research Station, Viti Levu, Fiji. NZ Soil Survey Report 78. Wellington, NZ: DSIR. 36 pp. http://doi.org/10.7931/DL1-SSR-78

[37] McLeod M. 1992. Soils of Dobuilevu Agricultural Research Station, Viti Levu, Fiji. NZ Soil Survey Report 84. Wellington, NZ: DSIR. 43 pp. http://doi.org/10.7931/DL1-SSR-84

[38] Palmer R.W.P. 1992. Soils of Naduruloulou Agricultural Research Station, Viti Levu, Fiji. NZ Soil Survey Report 82. Wellington, NZ: DSIR. 45 pp. http://doi.org/10.7931/DL1-SSR-82

[39] Purdie B.R. 1986. Soil Taxonomic Unit Descriptions for Wainigata Agricultural Research Station, Vanua Levu. NZ Soil Bureau Taxonomic Unit Descriptions 8. Wellington, NZ: DSIR. 48 pp.

[40] Rijkse W.C. 1990. Soils of Sigatoka Research Station, Viti Levu. NZ Soil Bureau Report 81. Wellington, NZ: DSIR. 58 pp. http://doi.org/10.7931/DL1-SSR-81

[41] Shepherd T.G. and Neall V.E. 1986. Soil Taxonomic Unit Descriptions for Vunilagi Estate, Vanua Levu, Fiji. NZ Soil Bureau Taxonomic Unit Descriptions 18. Wellington, NZ: DSIR. 49 pp.

[42] Shepherd T.G. and Neall V.E. 1991. Soils of Tutu Estate, Taveuni, Fiji. NZ Soil Survey Report 85. Wellington, NZ: DSIR. 111 pp. http://doi.org/10.7931/DL1-SSR-85

[43] Smith S.M. 1992. Soils of Waidradra Agricultural Research Station, Viti Levu, Fiji. New Zealand Soil Survey Report 83. Wellington, NZ: DSIR. 35 pp. http://doi.org/10.7931/DL1-SSR-83

2.4 National soil survey, 1981–1984

In 1981, Dave Leslie was seconded for three years to New Zealand Ministry of Foreign Affairs (MFA) and attached to the Land Use Section, MPI, Fiji, working with Vilitati Seru to coordinate and correlate the National Soil Survey of Fiji.

The 1980–1982 soil surveys of the nine ARS, Tutu and Vunilagi Estates, and Rotuma provided detailed representative windows into the Fiji soil pattern. Mapping was onto recent aerial photos used to produce 1:50,000 topographical maps of the country then transferred onto 1:25,000 compilation sheets with a final map at 1:50,000. Maps have not been printed but have been digitised as part of the Fiji Soil Crop and Evaluation Project (SCEP) and are available on request from the Land Use Section, MPI, and the Fiji Land Information Centre. The national soil survey comprised 525 soil mapping units and 227 soil series.

In the physiographic legend soil series, soils of the lowlands and foothills are initially separated from those in the uplands to reflect the change in soil temperature regime at 600 m altitude, namely isothermic soil temperature regime (STR) above 600 m altitude and isohypothermic STR below. The second-level separation groups soils into major landform categories (e.g., soils of the marine marshes). Soils are further differentiated based on their parent material, then on their internal drainage class. Where appropriate, a final differentiation is made based on the soil moisture regime (SMR) under which they fall. Fiji has a good density of rainfall stations and the boundaries between ustic, udic and perudic SMR could be precisely drawn, and they match closely the wet and dry season categories of Twyford and Wright (1965).[44]

FIGURE 5: GIS Training Workshop in 1983. Participants (from left to right): Vilitati Seru, Vilimaina Civavonovono, Kasaqa Tora, Prem Prasad, Peter Stephens.

[44] Seru V.B. and Leslie D.M. 1986. Soil map of Fiji. Scale 1:50,000. Land Use Section, Land Resource Planning and Development Division, Ministry of Agriculture, Fiji.

Two volumes of STUDs were published for the 227 soil series recognised for Fiji, each following the standard 3–4-page Soil Bureau STUD format.[45]

Most soil analyses were undertaken at Koronivia Research Station by Jone Korovou, William Magnus, Bardu Singh and Toka Tunidau. Clay mineralogy and chemical and physical analyses required for classification according to Soil Taxonomy were conducted at NZ Soil Bureau by Brian Daly, Keitha Giddens, Lee Searle and Joe Whitton under the supervision of Les Blakemore. Dave Leslie and Vilitati Seru had field and cartographic assistance from Epeli Draniikamate, Moape Naiseru, Sakiusa Navatu, Atish Prasad, Timoci Qeisene, Inoke Ratukalou and Kasaqa Tora.

Soil chemist Dr John Morrison, University of the South Pacific (USP), was contracted by the Fiji Pine Commission to look at nutritional aspects of *Pinus caribbea* growth in permanent sample plots at their Nabou, Lololo and Nadi forests in western Viti Levu. Dave Leslie, assisted by Keith Nakatani, a Peace Corps volunteer attached to the Fiji Pine Commission, undertook detailed soil descriptions at the permanent sample plots and collected samples that were analysed at the USP Institute of Natural Resources laboratory.[46,47,48]

In November 1981, John Morrison and Dave Leslie organised the South Pacific Regional Forum on Soil Taxonomy, which was co-sponsored by the Institute of Natural Resources and the Soil Management Support Services (SMSS), Soil Conservation Service (SCS), United States Department of Agriculture (USDA). The Forum and participants from Fiji, Papua New Guinea (PNG), Cook Islands, Solomon Islands, Niue, Samoa and Tonga were funded by the United States Agency for International Development (USAID). Twelve observers and resource persons attended, including Dr Hari Eswaran and Richard Kover from SMSS, USDA; Marc Latham, ORSTOM; Goro Uehara, University of Hawaii; Mike Leamy and Fletcher Thomas from NZ Soil Bureau, DSIR; and John Morrison and Dave Leslie. Twenty described pedons were visited in the field and their classification thoroughly discussed at each site.

[45] Leslie D.M. and Seru V.B. 1998. Fiji Soil Taxonomic Unit Description Handbook (2 volumes). Lincoln, NZ: Manaaki Whenua Press. 928 pp.

[46] Leslie D.M., Nakatani K., Tora T., Magnus W., Prasard R.A. and Morrison R.J. 1985a. Soils of the Fiji Pine Forests. 2. Soils of the Nabou Forest. Environmental Studies Report 25. Institute of Natural Resources, University of the South Pacific. 63 pp.

[47] Leslie D.M., Nakatani K., Tora T., Magnus W., Prasard R.A. and Morrison R.J. 1985b. Soils of the Fiji Pine Forests. 3. Soils of Lololo Forest. Environmental Studies Report 26. Institute of Natural Resources, University of the South Pacific. 55 pp.

[48] Manner H.I., Nakatani K., Tora T., Leslie D.M., Prasard R.A. and Morrison R.J. 1985. Soils of the Fiji Pine Forests. 1. Soils of the Vatuma and Masi catchments, Nadi Forest. Environmental Studies Report 24. Institute of Natural Resources, University of the South Pacific. 71 pp.

FIGURE 6: Participants during a Soil Taxonomy Forum field trip.[49]

Dave Leslie carried out collaborative soil studies with numerous Fiji-based organisations and institutions, including SPC; the Fiji Sugar Corporation; Native Lands Development Corporation; Institute of Natural Resources, USP; South Pacific Applied Geosciences' Commission (SOPAC); Batiri Citrus Farm, Vanua Levu; and Yalavou and Yaqara cattle schemes. He also conducted a detailed survey soil survey at Narsarowaqa, Vanua Levu – a proposed broad-acre pigeonpea project funded by Australian Aid (AusAID) – working with George Raymond, Queensland Department of Primary Industries, Australia, who undertook the soil analyses.

Vilitati Seru and Dave Leslie also assisted a German soil science student studying soils of the saline marshes at Dreketi, Vanua Levu, where mangroves were being cleared for irrigated rice. These most interesting soils (sulfaquents, sulfaquepts) enabled soil changes (e.g., jarosite formation) to be observed as the soils ripened. Leslie assisted a team from the World Bank evaluate the soils on a small island within the lagoon east of Vanua Balavu Island which was being considered as a quarantine facility for foreign coconut planting materials. He flew to the island landing uphill (15° slope) on a very short runway – the plane always took off downhill.

These various studies involved some adventurous travel. One highlight for Dave Leslie was flying on a RNZAF C-130 aircraft at low altitude for about 1½ hours around Fiji leaning out the door on a parachute harness taking oblique landscape photos through the open door. He had a black and white and a colour camera and took over 300 photos from the flight that circled Vanua Levu, Viti Levu and Taveuni.

[49] Morrison R.J. and Leslie D.M. (eds) 1992. Proceedings of the South Pacific Regional Forum on Soil Taxonomy, Suva, Fiji, 2–13 November 1981. Suva, Fiji: Institute of Natural Resources, University of the South Pacific. 445 pp.

2.5 South Pacific Agricultural Chemistry Network (SPACNET)

By 1992, calls were being made for quality assurance of soil analysis in the Pacific region by the International Bureau of Soil Resources and Management (IBSRAM) at a meeting organised by the Fertilizer Advisory, Development and Information Network for Asia and the Pacific (FADINAP) in Thailand in August 1992, and by ORSTOM at a seminar on soil fertility in small Pacific Islands held in Noumea in November 1992. Accordingly, the South Pacific Agricultural Chemistry Laboratory Network (SPACNET) was established in November 1993 by Jean Petard, then Chef du Laboratoire, ORSTOM, Noumea and Brian Daly, Landcare Research, who at that time was an agricultural chemistry consultant funded by New Zealand's Ministry of Foreign Affairs and Trade (MFAT) and based at the Ministry of Agriculture Chemistry Laboratory, Koronivia Research Station, Fiji. MFAT was the sole donor for SPACNET activities over its first three years (1997–2000), with funds transferred to IBSRAM, Bangkok, which contracted Landcare Research to manage the financial and logistical inputs through Dave Leslie (Project Manager) and Brian Daly (Technical Coordinator). Landcare Research was contracted directly by MFAT for implementation of SPACNET Phases 2 and 3 (2001–2007).

The SPACNET member laboratories included: National Analysis Laboratory, Unitech, Lae, PNG; National Agricultural Research Institute (NARI), Boroko, PNG; Sugarcane Research Centre, Lautoka, Fiji; Institute of Applied Science, USP, Suva, Fiji; Koronivia Research Station, MPI, Fiji; Analytical Laboratory, MAF, Tonga; Analytical Laboratory, USP, Apia, Samoa; and Landcare Research, Palmerston North, NZ. Unfortunately, the MAF laboratory at Dodo Creek, Solomon Islands had been burnt to the ground during the period of civil unrest in 1998.

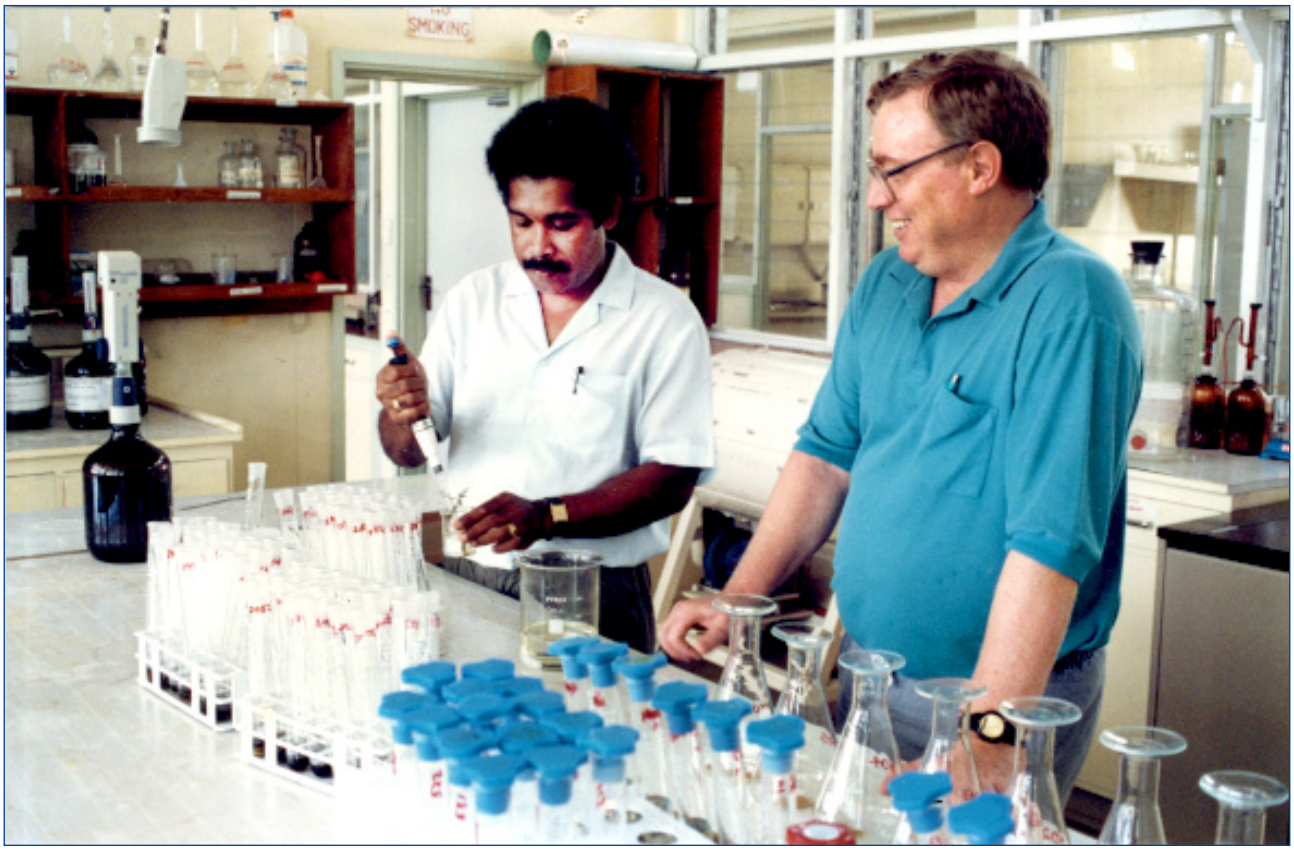


FIGURE 7: Participants of the SPACNET Project: Josua Wainiqolo and Brian Daly.

In February 1997, Brian Daly conducted an initial overview and needs assessment through visits to the member laboratories, and his report helped shape the priority activities for SPACNET. The overall project purpose was to enhance the quality of soil and plant analysis of the participating laboratories, with specific objectives of developing quality assurance programmes, including: strengthening soil and plant exchange networks; documenting standard methodologies for soil and plant analysis and quality control; identifying two laboratories as centres for the provision of regional analytical services and the training of technicians (Nari, PNG and Koronivia Research Station, Fiji were selected); developing links with a laboratory in a metropolitan country to support the quality assurance programmes (Landcare Research, New Zealand was chosen); and joining an international organisation operating a sample proficiency programme for soil and plant analysis (the Australian Soil and Plant Analysis Council [ASPAC] was chosen because of the 50 participating Australian laboratories).

Five Laboratory Managers workshops were held at different laboratories (including in Brisbane) on average every two years and each involved Brian Daly as the key resource person and on two occasions, soil chemist George Raymond, Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia, attended. These meetings provided brief overviews of the respective laboratories, including staffing and equipment details, and managers were able to appreciate the opportunities and problems confronting SPACNET while contributing to the information sharing process. Six training courses were held over the 10 years of SPACNET's operation, each of three weeks' duration for four laboratory technicians. These covered quality assurance systems, data interpretation and fertiliser advice laboratory management systems, and methodologies of soil and plant analysis. Twelve individual three-week secondments to different laboratories were held to gain skills in methodologies or modern equipment. As most laboratories needed to update method manuals and only half had quality assurance manuals, a generic quality assurance manual was written and supplied in electronic form to the laboratories.[50]

A recommended methods manual was also prepared and distributed with methods chosen for use in laboratories having a relatively low level of equipment and resources. A pH meter, electrical conductivity meter, visible spectrophotometer and a basic atomic absorption spectrophotometer were the only instruments needed.[51]

In 2003, a generic safety manual was distributed to laboratories in response to requests from laboratory managers who did not have the time or resources to write their own manual.[52]

An interpretation manual was produced to help with interpreting analytical data from laboratories in response to demand from agricultural extension officers and others, such as laboratory analysts in a quality assurance role who need to determine whether analysis results are within expected ranges.[53]

Ongoing checks of laboratory proficiency through sample exchanges is an essential part of every laboratory's quality assurance programme. Eight laboratories were involved in the exchange of four soil and plant samples over three rounds organised by the Australian Soil and Plant Analysis Council (ASPAC). The first two rounds in 1995 showed two of the regional laboratories were already producing high-quality data, and since then, considerable improvement has been achieved and tracked.

In 2010, NZ MFAT decided the region should take financial ownership of SPACNET. Although the Director General of SPC made a commitment to include SPACNET in its work programme at the current funding rate, this has never happened. Over its lifespan, SPACNET published 23 technical reports.

[50] Daly B.K. 2000. South Pacific Agricultural Chemistry Laboratory Network (SPACNET). Generic quality assurance manual for plant for soil and plant laboratories. Landcare Research International Business Group Report 208. Lincoln, NZ: Landcare Research. 72 pp.

[51] Daly B.K. and Hill L.F. 2002. Recommended methods for soil, plant and water analysis. South Pacific Agricultural Chemistry Laboratory Network (SPACNET). 120 pp.

[52] Hill L.F. and Daly B.K. 2003. Generic laboratory safety manual (SPACNET). Landcare Research International Business Group Report 320. Lincoln, NZ: Landcare Research. 29 pp.

[53] Daly B.K. and Manu V. 2003. Guide to interpretation of agricultural sample analysis results. Soil, plant and irrigation water. SPACNET. Landcare Research International Business Group report 315. Lincoln, NZ: Landcare Research. 31 pp.

2.6 Fiji Soil and Crop Evaluation Project (SCEP), 1983–1999

Dave Leslie conceived the concept for the Fiji Soil and Crop Evaluation Project (SCEP) as there had been no significant agricultural development following completion of the soil surveys of the Cook Islands, Niue and Tonga, which had produced a wealth of soil information (detailed soil maps, full characterisation and soil classification, laboratory analyses and agronomic data based on glasshouse and field experiments). The overall goal of the programme was to contribute to self-sufficiency in food crops, with an increase in export earnings for Fiji through documentation and demonstration of crop nutrient requirements on the soils suitable for sustainable cropping systems.

The phase one programme of SCEP was implemented in 1983–1987. Modelled on the USAID-funded Benchmark Soils Project developed by the University of Hawaii, it involved crop- and soil-specific field trials to evaluate soil fertility and nutrient and economic requirements for nationally important cash and subsistence crops. A key objective was to develop predictive soil and crop management models farmers could use. To ensure the five-year programme was robustly designed, international scientists joined John Widdowson and Dave Leslie (Project Director) on the design panel. These included Dr Jim Silva, agronomist, University of Hawaii; Dr Paul Haydock, biometrician, CSIRO; Dr Paul Gregg, soil scientist, Massey University; and Ian Ward, crop specialist, CSIRO. Gary Osborne, soil chemist, New South Wales Department of Primary Industries, Australia, was appointed initial Project Manager. Minimum datasets were identified as part of the project experimental design. Trial sites with fully characterised soils were established at Koronivia, Sigatoka, Seaqaqa and Legalega research stations. Agronomic and laboratory staff were trained in Fiji and New Zealand. The Fijian agronomists were Kamlash Puran, Kaniappa Reddy and Narayan Reddy. The project was jointly funded under the NZ Bilateral Aid Programme by NZ MFAT (DSIR Land Resources managed the MFAT inputs) and AusAID (ACIL Australia Pty managed the AusAID inputs) with the Research Division of Fiji MPI.

FIGURE 8: Participants of a SCEP Review field trip: Sant Kumar, Mohammed Iqbal, Nand Kumar, Makelesi Tavaiqia, Jainendra Kumar, Param Sivan.

Bruce Trangmar and Gary Osborne conducted an experimental-methods training course for SCEP in September 1986, and a number of publications were produced as SCEP reports or in the Fiji Journal of Agriculture. The project was terminated following the Fiji coup in 1987 and withdrawal of aid funding. AusAID requested a review of SCEP, which was undertaken by Bob Thistlethwaite (AusAID), Dave Leslie, Gary Osborne (SCEP Project Manager), Navin Patel (Director, MAF, Fiji) and Param Sivan (Director Agriculture Research, MAF, Fiji).[54,55]

[56]

FIGURE 9: SCEP project review. Participants in the field at Nadarivatu, Viti Levu Highlands.

[54] Silva J.A., Gregg P., Haydock K.P., Leslie D.M., Widdowson J.P. and Wood I.M. 1984. A proposal for Fiji Soil and Crop Evaluation Project. NZ Soil Bureau Scientific Report 65. Wellington, NZ: DSIR. 124 pp. http://doi.org/10.7931/DL1-SBSR-65

[55] Trangmar B.B. and Osborne G.J. 1987. Fiji SCEP experimental methods training course (22 Sept–3 Oct 1986), Suva, Fiji. Fiji SCEP Technical Report 1. 33 pp.

[56] Thistlethwaite R.J., Leslie D.M., Osborne G., Patel N., Sivan P. and Wood I.M. 1989. Review of Fiji Soil and Crop Evaluation Project (Fiji SCEP). Fiji SCEP Technical Report 2. 170 pp.

The Fiji Soil and Crop Evaluation phase two programme was implemented in 1993–1999, building on and continuing the services provided in phase one. The project was coordinated from the Fiji Ministry of Agriculture, Fisheries and Forests (MAFF) Koronivia Research Station – Research Division (laboratory and agronomy components) and Land Use Section (GIS component) – with ongoing field experiments at Sigatoka, Legalega, Koronivia and Seaqaqa Agricultural Research Stations. The project was again jointly funded under the NZ Bilateral Aid Programme by NZ MFAT and AusAID, with the Research Division of Ministry of Agriculture and Forestry, Fiji (MAFF). A key objective of the project was to assist the Research Division with institutional strengthening and technology transfer mechanisms. To facilitate this, ACIL Australia Pty Ltd provided frequent short-term inputs from extensionists, agronomists and training advisors. John Widdowson was the team leader in Fiji for the first three years, succeeded by Simon Field, ACIL, then John Riches, also from Australia.

In 1994, David Giltrap assessed the requirements and design for establishing databases for trial results and farmer practices, with integration of these with other relevant databases. He also assessed GIS and software requirements, designed an appropriate system to be housed with the Land Use Section, including maintenance and data security procedures, and facilitated the requirements for procurements. On subsequent visits, Giltrap, accompanied by Julian Cone (GIS specialist, Landcare Research), trained five Land Use Section staff in database and GIS operations and applications, oversaw the digitisation of the National Soil Survey and other resource data for GIS, and established user access procedures.

Brian Daly was attached to the Fiji Agricultural Chemistry Laboratory (FACL) at Koronivia Research Station for three years to provide hands-on training in methodology, results interpretation and equipment/instrument maintenance. He assessed training needs in soil and foliar analyses and developed a training programme in which 7 two-month training courses in soil chemistry were undertaken for Fiji MAFF laboratory technicians at NZ Soil Bureau, DSIR. Daly was a key facilitator in the South Pacific Agricultural Chemistry Network (SPACNET).[57,58,59,60,61]

John Claydon also conducted three training courses at Koronivia in methods of particle size analysis and water release and solid/void characterisation of soils.[62,63]

Rick Jackson visited Koronivia to procure equipment and train SCEP staff in use of the neutron probe for soil moisture monitoring. He oversaw the installation of aluminium access tubes at the experimental sites and analysed the results from regular monitoring.

In response to an AusAID request, Dave Leslie prepared a booklet on Fiji's soils for use in schools. This was distributed to all schools and has been reprinted and used as a training text at the University of the South Pacific.[64]

[57] Daly B.K. and Hine P.T. 1994. Fiji Agricultural Chemistry Laboratory quality assurance manual. FACL Technical Report 01/94. 70 pp.

[58] Daly B.K. and Wainiqolo J.L. 1993a. Methods of analysis for agricultural samples: Soil, plant, animal feed and water. FACL Technical Report 03/93. 115 pp.

[59] Daly B.K. and Wainiqolo J.L. 1993b. Guide to interpretation of agricultural sample analysis results: Soil, plant, animal feed, irrigation water and others. FACL Technical Report 04/93. 32 pp.

[60] Daly B.K., Wainiqolo J.L., Chand K. and Hart P.B.S. 1996. The microbial biomass carbon for monitoring organic matter dynamics under cropping and agroforestry in two Fiji soils. Fiji Agricultural Journal 1: 35–41.

[61] Daly B.K., Wainiqolo J.L., Field S.P. and Widdowson J.P. 1994. Guide to fertilisers: Composition and calculations. FACL Technical Report 02/94.

[62] Claydon J.J. 1993. Laboratory methods for water release and solid/void characterization of soils. FACL Technical Report 05/95.

[63] Claydon J.J., Daly B.K. and Wainiqolo J.L. 1993. Methods for particle size analysis of soils. FACL Technical Report 10/93. 17 pp.

[64] Leslie D.M. 1997. An introduction to the soils of Fiji. Fiji SCEP, Ministry of Agriculture. Suva, Fiji: AusAID. 182 pp.

2.7 Review of Rural Land Use and Land Use Policy, 1998–2002

The destruction of Fiji's natural resources and the threat to Fiji's predominantly agrarian-based economy due to growing industrial development led the Fiji government to call for an overall, broad, long-term land use policy and plan.

In 1998, German Technical Cooperation (GTZ), through their Pacific Regional Forestry Project (Evelyn Reigber, GTZ Team Leader) in collaboration with the Department of Land Resources Planning and Development (DLRPD) MPI, Fiji, provided the funds for Dave Leslie and Inoke Ratukalou (Director, DLRPD) to undertake the Review of Rural Land Use in Fiji and develop a Rural Land Use Policy for Fiji.

The review described the:

- Many previous studies and reports
- Land and water legislations
- Issues and impacts of good and bad land use practices
- Land use planning participatory processes
- Availability of information on land resources
- Need for external assistance to implement new projects to address important issues before the national rural land use policy and plan could be drawn up
- Steps for the proposed land use planning process
- Preferred institutional framework for land and water management and land use planning
- Rural management legislation for Fiji

The authors conducted several stakeholder meetings to discuss drafts of the review and policy. Invaluable comments were received from officials in the various government ministries, state-owned enterprises, non-governmental agencies and the private sector.[65]

The Land Use Policy Statement examined the constraints and issues and the need for the policy and outlined a land use vision, rural land use policy principles and nine proposed national policies. Appendices include statements about rural land use sector roles in the current national strategies and objectives. The Government of Fiji endorsed the Land Use Policy in 2005.[66]

[65] Leslie D.M. and Ratukalou I. 2002a. Review of Rural Land Use in Fiji – Opportunities for the New Millennium. Ministry of Agriculture, Sugar and Land Resettlement and the Secretariat of the Pacific Community/German Technical Cooperation. Noumea, New Caledonia: SPC. 175 pp. https://spccfpstore1.blob.core.windows.net/digitallibrarydocs/files/c0/c03b6d54f54f5665ed8a52d8a15242e6.pdf

[66] Leslie D.M. and Ratukalou I. 2002b. Rural Land Use Policy Statement for Fiji. Ministry of Agriculture, Sugar and Land Resettlement and the Secretariat of the Pacific Community/German Technical Cooperation. Noumea, New Caledonia: SPC. 32 pp. https://spccfpstore1.blob.core.windows.net/digitallibrarydocs/files/1e/1e62f15ca42cf7a721d6c7e023a261d2.pdf

FIGURE 10: Soil classification in the field during a 2004 Soil Taxonomy workshop. Kaliova Tunabuna, Patimio Tabuatalei, Mereani Rokotuibau, Vilimaina Civavonovono, Tuverea Tuamoto, Prakash Chandra.

2.8 A Reference Manual for Utilising and Managing the Soil Resources of Fiji, 2012

In 2012, Dave Leslie was contracted by SPC and funded by the European Union to prepare a soil resources manual for Fiji. The publication brings together all available relevant soil and land information to provide a broad framework for understanding and interpreting the soil resources of Fiji. It is designed for use by farmers, extension officers, researchers, agri-business managers and land-use planners.

The manual provides:

- Physiographic soil legends with mapping units and soil series hierarchically organised according to temperature and moisture regimes, landscape type, composition and degree of weathering of parent material and finally drainage classes
- Classification of soil series according to Soil Taxonomy and the FAO/UNESCO systems
- Flow diagram key to identification of soil series in a hierarchical order regarding the physiographic legends
- Soil mapping units and land use capability classes in the main soil limitations
- Land and soil attributes significant for crop growth for each soil
- Fertility capability soil classification of soils
- Soil attributes matched with crop requirements, expressed in one of four classes of crop suitability.

Based on this analysis, GIS-generated single-factor crop suitability maps were produced.[67]

FIGURE 11: Participants at the Land Use Planning Workshop in 2004.

[67] Leslie D.M. 2012a. A reference manual for utilising and managing the soil resources of Fiji. Secretariat of the Pacific Community. Noumea, New Caledonia: SPC. 164 pp. https://pafpnet.spc.int/attachments/article/170/Manual%20for%20Utilising%20Soil.pdf

Dave Leslie also provided the Department of Economic Planning and Statistics, MAFF with crop gross margin budgets for 55 crops able to be updated for production, commodity and labour costs on a regular basis and made available to end users.[68]

Based on the crop suitability analysis, James Barringer (Landcare Research) used GIS to generate 55 single-factor maps.[69]

In 2019, Dave Leslie compiled the soil analysis data for Fiji into a manual to assist scientists, agricultural officers, teachers, land use advisers and managers who require detailed information on the soil resources of Fiji.

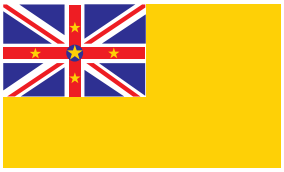
The soil analysis data completed the soil resources information for Fiji generated through the NZ-funded National Soil Mapping, Correlation and Classification project, implemented 1980–1985. The manual complemented the other project outcomes: The National Soil Map (Seru and Leslie 1986), the Soil Taxonomic Unit Descriptions (Leslie and Seru 1998) and the user-friendly soil resources manual (Leslie 2012).

The data represent the outcomes from a very significant 5-year analytical programme involving more than 20 analysts from five laboratories – Fiji Analytical Chemistry Laboratory, Koronivia; Institute of Natural Resources, University of the South Pacific, Suva; Queensland Department of Primary Industries, Australia; NZ Soil Bureau, DSIR; and Massey University, New Zealand.[70]

[68] Leslie D.M. 2012b. Gross margins for selected fruit, vegetable and root crops for the sugarcane belt in Fiji. Secretariat of the Pacific community. Noumea, New Caledonia: SPC. 56 pp. https://lrd.spc.int/pafnet-publications/doc_download/2242-gross-margins-for-selected-fruit-vegetable-and-root-crops-for-the-sugar-cane-belt-in-fiji

[69] Leslie D.M. and Barringer J.F.R. 2012. Suitability maps for selected fruit, vegetable and root crops for Fiji. Secretariat of the Pacific Community. Noumea, New Caledonia: SPC. 56 pp. https://lrd.spc.int/pafnet-publications/doc_download/2251-suitability-maps-for-selected-fruit-vegetable-and-root-crops-in-fiji

[70] Leslie D.M. 2021. Chemical and physical properties of Fiji soils: analytical data. Manaaki Whenua – Landcare Research contract LC3935. Lincoln, NZ. 256 pp. http://digitallibrary.landcareresearch.co.nz/digital/collection/p20022coll13/id/810



3. History of soil research in Niue

Since 1958, when Morice Fieldes of the New Zealand Soil Bureau discovered the incidence of high natural radioactivity in Niuean soils, the Soil Bureau has maintained a continuing interest in the study of Niue's soils, particularly their possible origin.

3.1 Initial soil survey of Niue, Grange 1938

The first appraisal of the soils of Niue was made in 1938 by Les Grange, Director of the Soil Survey Division of the Department of Scientific and Industrial Research (DSIR).[71]

Early soil analyses conducted by DSIR (Birrell et al. 1939) showed the soils were composed mainly of aluminium and iron oxides and were unusually low in silicon (usually < 1%). Soils were underlain by limestone of unusual purity (commonly > 99% calcium and magnesium carbonate). There was such a wide variation in the levels of available plant food that it was decided to make a complete inventory of the soil resources of Niue.[72]

3.2 Soil reconnaissance survey of Niue, Wright 1949

Charles Wright carried out the reconnaissance soil survey in April–May 1949. No recent land survey data was available at that time, and it proved necessary to traverse fairly accurately all across island roads and major tracks to provide an adequate framework for the soil map. These, and the soil boundaries, were plotted onto an earlier map of Niue prepared by NZ Lands and Survey Department in 1903. In the absence of elevation points on the island, the soil survey was made by pace and compass methods. In this reconnaissance soil survey, Wright was greatly assisted by the farmers of Niue, who had a good knowledge of their own soils and had precise words in the Niue language to describe of soil colours and textures.

Soil samples and soil monoliths were taken to NZ for laboratory analysis, as were several bulk samples for use in pot experiments to determine soil fertility status.

This preliminary soil survey (Wright 1949, unpublished report) showed that the soil resources of Niue were barely adequate to support the population. The island had a plateau surface, surrounded by a narrow fringe of very rocky, sloping land. There were no true steepland soils, no alluvial soils or soils with a high-water table which might be adapted for wetland farming, and no supply of surface water from which irrigation systems might be devised. The Niuean farmers thus had little choice but to depend strictly on a system of shifting cultivation based wholly on the use of nutrient supply available from the forest residues.

The reconnaissance survey showed more than one third of Niue's 26,264 ha consisted of coral rock, significantly restricting the area available for planting crops. Furthermore, 6070 ha of soil were depleted almost to the point where they could no longer grow food crops without the addition of fertilisers. Within those 6070 ha, some 3240 ha were severely depleted soils and completely occupied by low fern – the Niuean 'desert wasteland'.

The problem of developing export crops was shown to be rather less urgent than the problem of finding out how the population were to feed themselves in the future.[73]

[71] Grange L.I. 1949. Soils of some Pacific islands. pp. 45–48 in Proceedings of the first Commonwealth conference on tropical and subtropical soils, 1948. Commonwealth Bureau of Soil Science, Technical Communication 46.

[72] Birrell K.S., Seelye, F.T. and Grange L.I. 1939. Chromium in soils of Western Samoa and Niue Island. New Zealand Journal of Science and Technology A 21: 91–95.

[73] Wright A.C.S. 1949. Soil reconnaissance of Niue Island. Unpublished DSIR Report.

3.3 Soil survey of Niue, Wright and van Westerndorp 1959–1960

The fieldwork for this soil survey was carried out by Charles Wright and supported by F.J. van Westerndorp (tropical agriculturalist) in 1959–1960. Chemical analyses were determined at NZ Soil Bureau by Les Blakemore, I. Hull-Brown, N.C. Ashman and V.A. Valk, mechanical analyses by R.Q. Packard and mineralogy by Morice Fieldes (Fieldes et. al 1960).

The 1:6,360-scale map of Niue showed a very complex and highly irregular soil pattern, yet there was a simple broad grouping of soils into four soil series – Hikutavake, Hakupu, Fonuakula and Palai – which could be clearly differentiated by the subsoil colours that from coast to inland ranged from very dark grey, through brown and reddish brown to dark red. Running parallel with the subsoil colour grouping, the topsoil textures changed from silt loam, through loam and silty clay loam to clay loam. Fieldes et al. (1960) found no correlation between the redness of the soil and haematite content and concluded the colour differences were due to surface and particle size effects rather than the nature and bulk of the crystalline iron oxides.

Charles Wright and F.J. van Westerndorp recognised within each of the four series a range of profiles depending partly on the depth of the soil over limestone, the amount of coral rock protruding the soil mantle and the degree to which ironstone concretions were developed in the soil. In the survey, soil mapping units were selected that effectively delineated the main variance within the series. For example, the soil map shows the Palai series and its subdivisions as 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.[74,75]

[74] Wright A.C.S. and van Westerndorp F.J. 1965. Soils and agriculture of Niue Island. NZ Soil Bureau Bulletin 17. Wellington, NZ: DSIR. 80 pp. https://doi.org/10.7931/7sjh-8k90; soil map: https://doi.org/10.7931/a51e-sc74

[75] Fieldes M., Bealing G., Claridge G.G., Wells N. and Taylor N.H. 1960. Mineralogy and radioactivity of Niue island soils. New Zealand Journal of Science 3: 658–675.

3.4 Soil fertility studies, Widdowson 1964

In 1963, because of declining crop yields, the Niue Agriculture Department sought the assistance of NZ Soil Bureau to investigate the causes of declining productivity in the shallow soils of Niue. John Widdowson visited Niue in April 1964 to seek field evidence of minor element deficiency; diagnose existing minor element deficiency using foliar sprays and soil applications of minor elements to existing crops; determine the available moisture storage and, if possible, evapotranspiration rates; and examine current fertiliser practice. Widdowson collected soil and plant materials for further soil fertility studies and microbiological analysis in NZ. Margaret di Menna examined the soils for yeasts, *Azotobacter* and nitrogen fixing *Clostridia*, and John Stout measured bacterial activity.[76]

John Widdowson's investigation concluded that crop growth was restricted by a shortage of available moisture due to low available moisture storage and uneven rainfall distribution. In soils where high quantities of calcium carbonate raised the pH above 7.2, crop growth was limited by zinc and iron deficiencies. Evidence also suggested that discing was responsible in many cases for enriching the topsoil with calcium carbonate and that crop failure on very shallow soils was related to the number of cultivations. The availability of major nutrients for crop growth were examined and recommendations concerning more efficient use of fertilisers were made. Where unthrifty crops did not appear to respond to nitrogen, phosphorus and potassium (NPK) fertilisers, deficiencies of minor elements were seen to be responsible. Widdowson recommended that more detailed field experiments were required to determine optimum rates of application of the major plant nutrients.[77,78,79,80,81]

3.5 Niue Soil and Land Use Programme, Leslie 1978–1979

In July 1978, Dave Leslie initiated the Niue Soil and Land Use Programme, spending six weeks on the island field checking the soil map of Wright and van Westerndorp (1965) through traverses and detailed mapping of selected windows. The field survey took 12 weeks over two periods in 1978 and 1979. The Niue government provided field assistants (Alapati Heka and Moleti Tamate) who assisted with soil description and provided local knowledge about land use and botanical identification. Traverses were pre-selected using the Wright and van Westerndorp soil pattern, geological information and landscape units differentiated from aerial photos. Most field time was spent describing dug soil pits and making auger observations (147 soil pit observations, 415 auger observations; one per 47 ha), predominantly along pre-selected traverses. The remaining time was spent mapping and sampling profiles for laboratory analysis. Free survey methods were employed with the density of observation varying as *tapu* areas and some heavily forested areas with difficult underfoot terrain (> 80% rock outcrop) were avoided. Soil series names established by Wright and van Westerndorp were retained, and the map unit boundaries correlated well between the two surveys. However, to apply the Soil Taxonomy classification system, nine new soil series had to be created, primarily due to applying the pedon concept, fundamental to the classification.

[76] Stout J. D. 1971. The distribution of soil bacteria in relation to biological activity and pedogenesis. Part 2. Soils of some Pacific Islands. New Zealand Journal of Science 14: 834–850.

[77] Widdowson J.P. 1965. Crop growth in relation to shallow calcareous soils, Niue. NZ Soil Bureau Report 3/1965. Wellington, NZ: DSIR. 43 pp. http://doi.org/10.7931/DL1-SBREP-65-3

[78] Widdowson J.P. 1966a. Zinc deficiency on the shallow soils of Niue. 1. Field investigations. New Zealand Journal of Agricultural Research 9: 44–58. https://doi.org/10.1080/00288233.1966.10418116

[79] Widdowson J.P. 1966b. Chlorosis in seedling *Crotalaria anagryoides* on a calcareous soil. New Zealand Journal of Agricultural Research 9: 261–267. https://doi.org/10.1080/00288233.1966.10420779

[80] Widdowson J.P. 1966c. Zinc deficiency on the shallow soils of Niue. 2. Effects of zinc sulphate on the yield and nutrient composition of crotalaria and sweetcorn. New Zealand Journal of Agricultural Research 9: 748–770. https://doi.org/10.1080/00288233.1966.10431564

[81] Widdowson J.P. and Watts H.M. 1977. Zinc deficiency on the shallow soils of Niue. 3. Response of sweetcorn to sources of zinc. New Zealand Journal of Experimental Agriculture 5: 241–248. https://doi.org/10.1080/03015521.1977.10425974

FIGURE 12: Participants of the 1979 soil training seminar.

The chemical analyses were carried out by Keitha Giddens, Earl Joe, Les Blakemore and physical analyses were conducted by Fletcher Thomas and Adrienne Hall at the Soil Bureau Taita Laboratory, New Zealand. Soils of Niue have very similar chemical properties. The pH levels are close to neutral; no strongly acid or strongly alkaline soils are found. Levels of calcium and magnesium are usually high or very high, although subsoil levels may be lower. Levels of potassium (Kc) are generally low or very low, and reserves of Kc that can become available in future from weathering are negligible. Phosphorous (P) is very high in all soils but very high P retention figures suggest P availability is limited, although P held at neutral pH (largely by calcium) appears to be available in adequate quantities for crops. Zinc is generally low and often below the critical level of 1.4 ppm. Levels of cation exchange capability, potassium and zinc are closely linked to organic matter.[82,83]

[82] Leslie D.M. 1986a. Soil map of Niue Island. Scale 1:50,000. NZ Soil Bureau Map 228. Wellington, NZ: DSIR. https://dx.doi.org/10.7931/fyct-3x74

[83] Leslie D.M. 1986b. Soil taxonomic unit descriptions for Niue. NZ Soil Bureau Soil Taxonomic Unit Descriptions 19. Wellington, NZ: DSIR. 81 pp.

3.6 Soil classification of Niue soils according to Soil Taxonomy, Leslie 1986

Application of Soil Taxonomy necessitated establishment of the number of soil series, primarily because the mineralogy and particle size classes were differentiated. The soil pattern of concentricity matches that of Wright and van Westerndorp, but the pattern is more complicated, in part due to the occurrence of makatea (unconsolidated shelly or sandy lagoonal floor deposits) and frequency of pinnacled coral limestone outcrops. Soils belonging to the Mollisol and Inceptisol orders were further classified into eight subgroups.

Classification of soil series is as follows: Toi (Udic Haplustoll, very fine, crandallitic), Niufela (Udic Haplustoll, very fine, oxidic), Vaiea (Udorthentic Haplustoll, very fine, oxidic), Tumufa (Udorthentic Haplustoll, very fine, gibbsitic), Hikutavake (Ruptic-lithic Haplustoll, clayey, smectitic), Fonuakula (Oxic Haplustoll, very fine, gibbsitic), Fetiki (Ruptic-lithic Haplustoll, very fine, oxidic), Palai (Ruptic-lithic, very fine, oxidic), Hakupu (Ruptic-lithic Haplustoll, fine, crandallitic), Mutalau (Ruptic-lithic Haplustoll, very fine, oxidic), Foa (Ruptic-lithic Haplustoll, very fine, gibbsitic), Avatele (Udic Haplustept, fine, oxidic) and Tafolomahina (Ruptic-lithic Haplustoll, very fine, gibbsitic).

Wright and van Westerndorp (1965) faced difficulties attempting to classify the Niue soils into higher categories. They concluded the main soil process was essentially latosolic, and the soils were therefore latosols, but noted morphological and mineralogical similarities to the red-brown loams of New Zealand. Wright and van Westerndorp proposed that, owing to their uniformly high base status, the soils should form a special category of latosols similar to the latosols of high base status mapped in Fiji. They suggested the black Hikutavake soils be classified as 'tropical rendzinas' or 'tropical black earths', although noting similar soils in Fiji had been classified as 'nigrescent' (Twyford and Wright 1965). This illustrates the need for a Soil Taxonomy system that can assign soils to defined classes reflecting both soil genesis and land use. In many Niuean soils, the lithic contact fluctuates from the soil surface to 1.5 m depth above and below 50 cm depth at short intervals. This pattern markedly influences classification when applying the definition for pedons.

Soil Taxonomy acknowledges the problems of classifying soils with "discontinuous horizons or horizons that are greatly variable in thickness or other properties", concluding that "trouble can be avoided by arbitrarily saying the two soils are present if a diagnostic property or horizon present in some spots is missing in others" and advocates setting a minimum limit to the area of "a soil", i.e., the pedon as "a clear unit for descriptions and for the selection of samples". The placement of both lithic and non-lithic soils in one series does not violate the taxonomic purity of the series or family. Other approaches would have such variability in the mapping unit, either as inclusions of the lithic soil in a non-lithic monotax unit, or a lithic-non-lithic complex. The provision of the ruptic adjective encapsulates the "true" field situation, within the defined limits for a pedon – Ruptic-lithic Haplustoll.

The reasonable availability of phosphate (from guano) in most Niue soils is associated with high calcium presence and near neutral pH, which have led to the formation of considerable amounts of crandallite. This mineral was highest in soil series occurring on the island's rim where bird populations would be greatest. Because of the high levels of crandallite in these soils, a case was made to the United States Department of Agriculture (USDA) to establish a new mineralogy class.

Niue soils satisfy criteria for an ustic moisture regime and criteria for the isohypothermic temperature regime.

The geographic isolation of Niue and the absence of non-calcareous rocks suggests the source of the parent materials for the soils has been either the accession of volcanic ash or volcanic ash with additions of trapped fine marine sediments. The characteristics observed in present-day soils can be explained if the sediments were influenced by submarine hydrothermal activity. The amount of coral disillusion necessary to produce the quantity of soil presently on the island is not compatible with the present-day topography. Either theory for the source of parent material must account for the following characteristics of the parent material: the elevated levels of natural radioactivity; the radio-disequilibrium between U-238 and Th-230; the high levels of mercury

(80–3000 ppm); the rare earth element distribution pattern, which shows depletion of caesium; the purity of the underlying coral limestone, implying a rapid deposition of soil material on the elevated atoll; and the absence of any volcanic rock on the island. The strongly weathered soils of Niue occur as a thin veneer up to 1.5 m deep. The average depth, however, is less than 30 cm over coralline materials. Dominant secondary minerals consist mainly of gibbsite, goethite, boehmite and crandallite, with silicon content being extremely low.[84]

3.7 Glasshouse pot experiments, Widdowson 1978

In New Zealand, John Widdowson and Agronomy Section staff (Harvey Watts and Frank Taylor) of NZ Soil Bureau undertook glasshouse experiments on soils to assess the plant nutrient status of representative Niuean soils. Green Panic (*Panicum maximum*) was grown for four months under glasshouse conditions simulating the Niuean climate. The grass was harvested four times at three-week intervals and its response to major nutrients (nitrogen, phosphorus, potassium and sulphur) and trace elements (zinc, manganese, molybdenum and iron) was examined using a subtractive technique.

The pot trials and chemical analyses showed organic matter levels were quite high, especially after bush fallow. Calcium carbonate enrichment diluted the nutrient content of soils and, by raising pH, reduced availability of minor elements such as zinc, manganese and iron. Available calcium, magnesium and phosphorus were high in all soils and do not need to be supplied in fertilisers. Available nitrogen increased in the soil under bush fallow but declined rapidly with cropping and must therefore be supplied in fertilisers. Potassium levels were 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 the pot trials but under field conditions, sufficient sulphur is added from sea spray to satisfy crop needs. Available zinc is low in most topsoil and declines to very low levels in subsoils, and zinc must be supplied to most crops.

3.8 Soil and Land Use Seminar, 1979

In October 1979 a seminar on soils and land use was held in Niue to discuss the results of the 1978 soil survey carried out by Dave Leslie under the Niue Soil and Land Use Programme and the laboratory analyses and glasshouse experiments. The seminar was conducted by Les Blakemore, Leslie, Bruce Miller and John Widdowson.[85]

The seminar was chaired by Morris Tafatu, Director of Agriculture, Niue and attended by 35 participants, of which 17 took part in a three-day soils course involving field trips to soil sites and farmers' fields. A separate report was presented to the seminar, which contained background information on the soils of Niue, including maps, the results of the 1978 soil survey and results from chemical and physical analyses and the glasshouse trials.[86]

Following the seminar, irrigation specialist John Blackwell, Institute of Biological Resources, Commonwealth Scientific and Industrial Research Organisation (CSIRO), joined the NZ Soil Bureau team to design a small-scale, low-cost irrigation system suitable for agricultural trials and to set up a USA class A pan evaporimeter and begin daily evaporation readings. He also determined infiltration rates on key Niuean soils and the physical soil characteristics pertinent to irrigation practice. Blackwell produced a useful report on this preliminary investigation for irrigation development.

[84] Leslie D.M. 1985. The classification by Soil Taxonomy of the soils of Niue. The South Pacific Journal of Natural Science 7: 100–131.

[85] Miller R.B. (compiler) 1980. Niue Soil and Land Use Seminar, Alofi, Niue, 9–11 October 1979. NZ Soil Bureau Report. Wellington, NZ: DSIR. 133 pp.

[86] Blakemore L.C., Widdowson J.P. and Leslie D.M. 1979. Soils of Niue Island. Interim report. NZ Soil Bureau, Lower Hutt. Wellington, NZ: DSIR. 59 pp.

3.9 Soil Radioactivity Project, 1990–1991

The soils of Niue Island have been known to be highly radioactive for more than 55 years. This radioactivity is unusual as large amounts of Th-230 are present with relatively little of the usual U-238 or U-234 (Fieldes et al. 1971; Whitehead et al. 1991; Whitehead et al. 1993).[87,88,89]

To help establish the origin of the anomalous radioactivity, Dave Leslie collected samples, based on a grid pattern, from 99 sites across the island. Samples were taken from all horizons above the underlying limestone and analysed at the Institute of Nuclear Sciences, DSIR, New Zealand for their radioactivity. Most of the analyses for major and trace elements were carried out by X-ray fluorescence analysis. The results are given in a technical report (Whitehead et al. 1991). Representative contour maps of elements were prepared, showing that high concentrations were greatest in the centre and north of the island. There are relatively large amounts of Pa-231 with little of the parent U-235. Separation of U-238 from its daughter products occurs during marine sedimentation. Products of rock weathering reaching the sea contain uranium and its disintegration products, but conditions are such that uranium tends to stay in solution while its daughter products, Th-230 and radium-226, are deposited by precipitation and absorption. Thus, in recent marine sediments, radium-226 is not in equilibrium with uranium. The existence of disequilibrium of this type in Niuean soils suggests that their radioactive constituents have been derived from seawater. Abyssal red clays from deep sea sediments have been reported to be high in radioactivity due to radium being out of equilibrium with other elements of the uranium family. Samples from the Pacific sediments are in the same range as those found in Niuean soils.

NZ Soil Bureau files from the 1950s show a most interesting correspondence between Dr Morice Fieldes and Sir Ernest Marsden, DSIR's Scientific Liaison Officer, then in the UK, about the origin and significance of this radioactivity.[90]

Dr Trevor Hatherton, Geophysics Division, DSIR, determined magnetic susceptibilities on samples collected by Charles Wright in 1949. All the soils tested contained magnetic particles demonstrated by X-ray diffraction to be mainly magnetite. Magnetite may be formed in various ways, but its formation in soils as a secondary mineral does not appear to have been reported, and it is assumed that the magnetite in the soils is of primary origin.

Whitehead et al. (1992) postulated the following sequence of geological events: 1) coral ceases growing in central lagoon of Niue; 2) the island remains mostly above sea level, and volcanic ash is added and weathers to goethite and gibbsite; 3) during one or more times of sea-level rise, the lagoon is briefly flooded and soils accumulate various elements, including uranium; 4) the island rises onto a tectonic ripple and is exposed subaerially; daughter products of uranium accumulate; 5) the island is now mostly too high to be flooded when sea level rises; 6) the island remains exposed subaerially, and leaching of uranium becomes intense and anomalous soil radio-activity is formed. Whitehead et al. concluded the anomalous radioactivity in Niuean soils was most likely due to absorption of uranium on pre-existing soils formed from highly weathered volcanic ash from dacite type volcanoes during at least one period when the island was briefly submerged. Following this, the island remained mostly above sea level until the present. During that time, the daughter products of uranium accumulated. After a change in weathering regime about 100,000–70,000 BP, the uranium was leached away leaving the daughter products present in far greater amounts than their parent radionuclides.[91]

87 Fieldes M. 1971. Significance of soils of Niue Island to soils formed on coral limestone in the Pacific. Record of Proceedings, 12th Pacific Science Congress, Canberra (1971) 1:2.

88 Whitehead I.E., Hunt J.L., Leslie D.M. and Rankin P.C. 1991. Determination of radioactivity and element concentration and soils from Niue Island. DSIR Land Resources Technical Record 57. Wellington, NZ: DSIR. 58 pp.

89 Whitehead I.E., Hunt J.L., Leslie D.M. and Rankin P.C. 1993. The elemental content of Niue Island soils as an indicator of their origin. New Zealand Journal of Geology and Geophysics 2: 243–254. https://doi.org/10.1080/00288306.1993.9514572

90 Marsden E., Ferguson G.J. and Fieldes M. 1958. Notes on the radio-activity of soils with application to Niue Island. Proceedings of the Second United Nations International Conference on Peaceful Uses of Atomic Energy 18: 514–515.

91 Whitehead N.E., Ditchburn R.G., McCabe W.J. and Rankin P. 1992. A new model for the anomalous radioactivity in Niue Island (South Pacific) soils. Chemical Geology 94: 247–260.

3.10 Niue Forestry Project, 2001–2003

The Niue Forestry Project, funded by NZ Overseas Development Assistance, arose out of the 1989 Niue Forestry Action Plan and was based on a 1990 Department of Agriculture Forestry and Fisheries (DAFF) discussion paper analysing changes in forest cover due to substantial clearing of secondary forest for taro production. In 2000, Landcare Research was awarded a management services contract by the NZ Ministry of Foreign Affairs and Trade (MFAT) to assist the Forestry Division, Niue to assess Niue's mahogany plantations and landowner concerns regarding leases, research and extension forestry. The project team comprised Michael Krausse (Project Manager), Dave Leslie, Terry Savage and George Kuru (Forestry/IT consultant). A forestry geographic information system (GIS) was established and accurate forest maps prepared for each leased forest, and Kuru installed a computer-based stand record and forest management system linked to the GIS. Savage used GIS to generate single-factor maps (soil depth, zinc and potassium levels, and soil profile features based on Leslie's soil survey) and compiled climate attributes relevant to assessing plant suitability. Site and productivity class maps for mahogany were completed. PLANTGRO software was used to identify potentially viable timber and crop species, predict performance and produce class suitability maps for each. SPOT4 was used to complete a current land cover map of Niue and complete an analysis of changes in forest cover between 1994 and 2001.

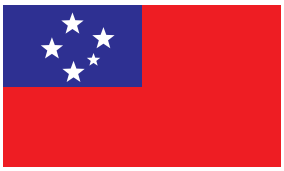
FIGURE 13: Participants of a soils and land use training workshop describe soils in the field (2015).

FIGURE 14: Group picture of participants of a 2015 training workshop on soils and land use.

3.11 Manual for Understanding and Managing Soil Resources, Leslie 2015

In 2015, Dave Leslie was contracted by the Food and Agriculture Organization (FAO) to compile a reference manual to provide agricultural extension officers, researchers, planners, farmers and others working in the rural development sector with a user-friendly guide to the field identification of soils, soil attributes important for crop growth, information about soil fertility, and an assessment of the suitability of the soils to grow a wide range of fruit and vegetable crops. Based on the crop suitability analysis, GIS was employed to generate single-factor maps for a range of fruit and vegetable crops and forest timber species.[92]

[92] Leslie D.M. 2015. A Reference Manual for Understanding and Managing the Soil Resources of Niue. Food and Agricultural Organisation of the United Nations. 75 pp. https://pafpnet.spc.int/attachments/article/549/Niue-Soils-Resource-Manual.pdf



4. History of soil research in Samoa

4.1 Initial reconnaissance soil survey, Hamilton and Grange 1938

Due to falling production per unit area of cocoa and coconuts, the New Zealand government requested assistance to investigate soil issues in Samoa. It is almost certain that some large German commercial organisations carried out soil investigational work during their years of occupation in 1900–1914, but no record of this could be found on files or in scientific publications.

Thus, the first record of a systematic soil survey in Samoa is that of Hamilton and Grange (1938), who examined the relationship between soils and agriculture, particularly with reference to the former German coconut estates (now belonging to the Samoa Trust Estates Corporation) and some coconut plantations on the lowlands in foothills of Upolu, where soils were examined in some detail. A rapid survey was also made of Savai'i. The surveys established that the soil showed a leaching sequence, dependent mainly on the age of the volcanic parent material, in which silica was progressively lost and the relative proportions of iron oxide, aluminium and titanium increased. The quantity of bases available for plant nutrition often related to the position of the soil and the leaching sequence, and Hamilton and Grange recommended phosphatic and potash fertilisers be used on most of the soils. Foliar analyses from cocoa trees showing poor growth indicated phosphate and potash deficiencies were likely the main factors restricting agricultural production. A broad classification termed the soils as laterites. The soils were unusual in their 8–12.5% titanium oxide content (related soils occur in Hawaii and are regarded as infertile). The report identified the need for further investigation of varying fertility within a soil type, the form of phosphate to be applied and the relationship of minor elements to growth and yield of trees.[93]

Fusion analyses were conducted in New Zealand by F.T. Seelye of the Dominion Laboratory and analyses of soils and cocoa leaves by L. Hodgson and H.O. Askew of the Cawthron Institute. Ken Birrell, Soil Survey Laboratory, determined phosphate absorption figures.[94,95]

[93] Hamilton W.M. and Grange L.I. 1938. The soils and agriculture of Western Samoa. DSIR Bulletin 61. Wellington, NZ: DSIR. 31 pp. https://samoapsp.landcareresearch.co.nz/resources/soil-surveys/

[94] Seelye F.T., Grange L.I. and Davis L.H. 1938. The laterites of Western Samoa. Soil Science 1: 23–31.

[95] Birrell K.S., Seelye F. T. and Grange L.I. 1939. Chromium and the soils of Western Samoa and Niue Island. New Zealand Journal of Science and Technology A21: 91–95.

4.2 Soil survey of Samoa, Wright 1956

The New Zealand (NZ) Soil Bureau provided a pedologist (Charles Wright) to conduct a soil survey of Samoa with the support of a soil chemist (Les Blakemore) and cartographer (Franz Tindall).

Soil survey work commenced in May 1956 and was completed in December of the same year. Charles Wright was assisted in the field by Palusila A'Ati and Eti Taia, and during the mapping on Savai'I, he was greatly assisted by David Kear and Bryce Wood of NZ Geological Survey, who were then conducting a geological reconnaissance of that island.

Mapping was on a scale of 40 chains to 1 inch on Upolu, the island with the greatest extent of agricultural development. The survey of Savai'i was at a scale of 1:63,630 since aerial mosaics and base maps satisfactory for the 40 chains to one-inch survey were not available. Eight sheets of soil maps at a scale of 1:40,000 were produced for Upolu and generalised soil maps (2 sheets on a scale of 1:100,000) for both Savai'i and Upolu. Land classification maps (scale 1:100,000) were drawn for both islands.

The soil survey bulletin is in five sections:

- Introduction
- Description of the main features of the environment, particularly those influencing soil behaviour and land use
- Soil formation, soil relationships and soil classification, including a general description of the main groups of soils making up the soil pattern of Samoa
- Soil fertility and how it can be used for land classification
- Other land use matters

Charles Wright conducted a reconnaissance soil survey of Tutuila (American Samoa) and prepared a sketch map (included in NZ Soil Bureau Bulletin 22), correlating soils with Samoa where the soils are similar.

Approximately 200 soil samples were collected for analysis, most of which were rapidly analysed using a technique devised by Les Blakemore and Alan Metson to provide a basis for preliminary advice, which was supplied to the Department of Agriculture while the survey was still in operation.

Subsequently, selected soil profiles were analysed in more detail by N.V. Bailey, F.A. D'Ath, W. Owers, M. Fitzpatrick, C.D. Sutton, M. Young, J.C. Jennings, S.J. Stevens and W.T.G. Johnson under the supervision of Les Blakemore at the NZ Soil Bureau laboratory, Taita, New Zealand.

Charles Wright considered all Samoan soils derived from basalt and basaltic parent materials, with one exception, which were latosolic soils, and differentiation thereafter has been made on stage of weathering (as expressed by depth, subsoil colour, silica content and, if known, the type of soil clay), and degree of leaching (as expressed by the pH and base status). The exception is soils on the lava beds of Savai'i dating from about 1760 onwards that are so weakly developed that they are lithosols.

The range within the Samoan latosolic soil group extends from weakly weathered, weak to moderately leached soils through to moderately to strongly weathered, very strongly leached soils. Soil leaching is relatively intense, particularly above 600 m, where a layer of very acid, raw humus is usually developed. Above 1200 m, all soils have a deep layer of raw humus and are very strongly leached. There are 90 soils mapped on the islands of Samoa, and 24 of these are steepland unstable soils with a very weak zonal impress. Many soils are stony and/or rocky, which restricts mechanical cultivation, but it is generally true that the more stones and rocks in the soil, the better its productivity.[96]

[96] Wright A.C.S. 1963. Soils and land use of Western Samoa. Wellington, NZ: DSIR. NZ Soil Bureau Bulletin 22. 191 pp. https://doi.org/10.7931/dl1-sbb-022

4.3 Soil survey of the Asau Block, Savai'i, 1965

The Asau Block, a 2500-ha area of Samoan government land, straddles the western part of Savai'i Island. Elevations range from sea level to about 900 m. To help assess the agricultural potential of the block, a soil survey of the area was carried out by Des Cowie, assisted by D.C. Kimpton, in September 1965. The Department of Agriculture provided Tom Mauitau and Situfu Tanielu as field assistants.

The soils were examined and mapped in terms of their morphology, nutrient status, slope, depth to underlying rock and stoniness of the ground surface. Samples of the major soils were collected and analysed by C.J. Pederson, NZ Soil Bureau. Aerial photographs and a provisional 1:20,000-scale topographical map were used to plot soil boundaries in the field. On the northern part of the block, soils were examined along the boundaries and on traverses across the block. On the southern and central parts of the block, soil examination was restricted to boundary lines of the forestry line as far as they were cut and marked because ground control was inadequate to make traverses. As a compromise, the soil boundaries plotted by Charles Wright in the 1956 soil survey were used for this part of the block, with minor amendments from observations during the survey.

The soils of the Asau Block are stony and relatively shallow. Because of this, soil horizons are not well developed and apart from the scoria cones, profile differences between soils were gradual and not well marked. The most evident difference is an increase in the peatiness of the topsoil with increasing elevation. There was also an overall decrease in the boulderiness and stoniness of the surface with increasing elevation. Des Cowie classified the soils of the Asau Block as latosolic, i.e., they have thin topsoil over reddish or red, deeply weathered material low in silica and high in sesquioxides. Using Wright's 1963 classification, the soils are transitional to low humic latosols if they formed under rainfalls of 2000–3000 mm, humic latosols with rainfalls of 3000–4000 mm, and hydric humic latosols with rainfalls of 4000–5000 mm or at elevations > 650 m.[97]

4.4 ADB Land Resources Planning Project, 1989

The NZ consulting firm ANZDEC Ltd, with the Department of Scientific and Industrial Research (DSIR) Division of Land and Soil Sciences, implemented the Land Resources Planning Project in Samoa, funded by the Asian Development Bank (ADB). The project ran from May to December 1989, with the project office at the Department of Lands and Survey. Project personnel included: cartographer Duncan McCormick (retired from DSIR Cartographic Division), resource economist Dick Burgess (NZ Ministry of the Environment), and DSIR Division of Land and Soil Sciences staff, including Dave Leslie (Team Leader/Land Use Planner), David Giltrap (GIS Specialist), Wim Rijkse (Pedologist), Malcolm McLeod (Pedologist) and Bruce Trangmar (Land Evaluation Specialist).

The project fully utilised the comprehensive bulletin and maps of Wright (1963); the soil survey delineations were not altered but new physiographic and soil taxonomic legends were prepared. There was extensive field checking of soil series and sampling for laboratory analysis to improve definition of soil series and, importantly, to facilitate classification according to Soil Taxonomy. Six sheets covering Upolu and Savai'i at a scale of 1:50,000 were prepared, plus six sheets of land capability maps and six sheets for the land tenure map at the same scale. Fifty copies of each of the three thematic map sets were printed by NZ Government Printer. Land use was determined from aerial photographs with field checking. Land tenure maps plotted cadastral boundaries between government, Samoa Trust Estate Corporation, freehold and customary lands.

[97] Cowie J.D. 1974. Soils of Asau Block, Savai'i, Western Samoa. NZ Soil Survey Report 21. Wellington, NZ: DSIR. 38 pp. (Includes soil map of Asau Block) http://doi.org/10.7931/DL1-SSR-21

The consultants conducted a week-long practical training course early in the project for about 28 participants. The course topics covered: soil forming factors, soil mapping, soil surveys and soil maps, introduction to Soil Taxonomy, methods of aerial photo interpretation, geographic information systems (GIS) and associated cartography, GIS and databases, and procedures for GIS data capture and transfer.[98]

Dick Burgess prepared crop gross margins for 17 enterprises, including plantation and smallholder operations and two forestry species – mahogany and *Eucalyptus deglupta*.[99]

David Giltrap designed the GIS, purchased the hardware and software, and installed the unit at the Department of Lands and Survey. With assistance from Ioane Patelo, he entered data, developed the databases and generated the thematic maps. Through the life of the project, the consultants undertook on-the-job training in land use planning, soil surveys, cartography, and GIS operations and applications. Wherever appropriate, an effort was made to facilitate institutional strengthening to the Department of Lands and Survey and the Department of Agriculture, Forests and Fisheries.[100]

FIGURE 15: GIS training in 1989. Dr David Giltrap and Patelo Ioane.

[98] Leslie D.M., Giltrap D.J., McCormack D. and Rijkse W.C. 1989. Training Manual. Auckland, NZ: ANZDEC. 54 pp.

[99] Burgess R.J. 1989. Crop and forestry enterprise gross margins. Auckland, NZ: ANZDEC. 58 pp.

[100] ANZDEC 1990. Land Resources Planning Study, Western Samoa. Final report. Division of Land and Soil Sciences. Wellington, NZ: DSIR. 147 pp.

4.5 Soil Resources Interpretative Manual, 2010

In 2010, Dave Leslie was contracted by the Global Environmental Facility of the World Bank to work on the agricultural component of the Integrated Climate Change Adaption in Samoa project. Anne Rasmussen (Ministry of Natural Resources and Environment) was Project Manager, and Tuulima Laiti (Ministry of Agriculture and Fisheries) was Agricultural Coordinator and Leslie's counterpart for the project. A primary output from the project was the Soil Resources Interpretative Manual (Leslie 2010), a user-friendly guide for agricultural extension officers and researchers, planners, farmers and others working in the rural development sector to the field identification of soils, soil attributes important for crop growth, information about soil fertility, and assessment of the suitability of soils to grow a wide range of fruit and vegetable crops.

The reinterpreted information in the manual was derived from the most comprehensive bulletin of Wright (1963) and the revision of his soil map with modern soil classification of soil series from the 1990 ADB Land Resource Planning Project. The manual provides:

- Physiographic soil legends with soil mapping units and soil series hierarchically organised according to temperature regime, landscape type, composition and degree of weathering of material and drainage class
- Classification of soil series according to Soil Taxonomy and the FAO / UNESCO system
- Flow diagram key to identification of soil series in a hierarchical order regarding the physiographic soil legends
- Land and soil constraints significant for crop growth presented for each soil mapping unit
- Assessment of soil fertility in the tropics with special reference to Samoan soils and their nutrient status
- Fertility capability soil classification of soil mapping units
- Soil mapping units matched with individual crop requirements and expressed in one of four classes of crop suitability[101]

Based on the crop suitability analysis, GIS was employed to generate 58 single-factor maps. The GIS work was carried out by Pau Ioane and Bismarck Crawley at the Ministry of Natural Resources and Environment.

Dave Leslie prepared a report containing a crop gross margin budget for the 58 crops. Budgets were influenced not only by general factors, such as production and commodity prices, yields, costs, etc., but also by individual characteristics of the different farming systems.[102]

[101] Leslie D.M. 2010a. Soil Resources Interpretive Reference Manual for Samoa. Government of Samoa. 103 pp.

[102] Leslie D. M. 2010b. Gross Margins for Selected Crops for Samoa. Government of Samoa. 63 pp.

5. History of soil research in the Kingdom of Tonga

In 1975, David Ives, the Department of Scientific and Industrial Research (DSIR), New Zealand (NZ), set up the Tonga Soil and Land Use Programme, which was based on the previous Cook Islands project and funded by the NZ Ministry of Foreign Affairs under the NZ Bilateral Aid Programme. Gary Orbell was responsible for its implementation, following David Ives' resignation. Orbell was soil correlator for all the island groups mapped. NZ Soil Bureau, DSIR supplied seven soil surveyors – Gary Beecroft, Alan Hewitt, Mike Laffan, Orbell (Team Leader), Wim Rijkse, Hugh Wilde and Alasdair Wilson – to conduct the soil surveys of 'Eua, Ha'apai and Vava'u island groups. The soil survey teams were assisted during soil sampling by Les Blakemore (soil chemist) and John Widdowson (agronomist). New Zealand laboratory support staff included Brian Daly, Keitha Giddens, Dean McGaveston and Janice Willoughby; agronomists Phil Hart and Harvey Watts; and mineralogists Graham Claridge and Joe Whitton.

The soil surveys prepared detailed (scale 1:25,000) soil maps of the three island groups and sampled soils for full chemical, physical and mineralogical characterisation at NZ Soil Bureau laboratory, Taita. Soil taxonomic unit descriptions (STUDs) for soil series identified, described and analysed were also prepared.

The soil survey of selected islands of the Vava'u group took some years to complete. Initial mapping on the islands of Vava'u, Okoa, Pangaimotu and Utangake was carried out by Gary Orbell as part of the 1969 Royal Society of New Zealand expedition marking the 200th anniversary of James Cook's scientific voyage to the Pacific.[103,104]

In 1975, Gary Orbell, Wim Rijkse and Mike Laffan completed the soil survey of the Vava'u group, which comprises the main islands of Vava'u, Kapa, Hunga, Nuupapu, Pangaimotu, Ovaka and Ofu islands. Transport between these islands was supplied by Tonga's Ministry of Agriculture and Forestry and the Tongan Defence Force.

The soil survey teams received great support from Tonga Ministry of Agriculture and Fisheries (MAF) staff, and Haneteli Fa'anunu, Tevita Halo, Siua Halavatau and Viliami Manu.

Typifying soil profiles were classified according to the United States Department of Agriculture (USDA) Soil Taxonomy.

Hugh Wilde, assisted by Alan Hewitt, carried out the soil survey of 'Eua Island, which lies 20 km SE of Tongatapu.

The soil survey report described the soils of 'Eua and the report was accompanied by a soil map.[105,106]

The soil survey of the Ha'apai group was carried out by Alasdair Wilson and Gary Beecroft. The Ha'apai group lies 150 km NE of Tongatapu and 150 km SW of Vava'u and comprises the islands of Ha'ano, Foa, Lifuka, Uiha, Ha'afeva, Tungua, Nomuka and Mango.

Soils were primarily derived from andesitic tephra, coral sands, andesite, limestone on low raised atolls, sand cays and raised volcanic islands. The most extensive soils are Hapludolls derived from andesitic tephra. Soil physical analyses show low bulk density and large available water capacity properties. The soils have good physical properties suited to a wide range of crops when nutrient limitations are overcome.[107,108]

[103] Orbell G.E. 1971a. Soil surveys – Vava'u and adjacent islands, Kingdom of Tonga. Royal Society of New Zealand Bulletin 8: 125–130.

[104] Orbell G.E. 1971b. Parent material and age sequences in soils derived from recent and late Pleistocene volcanic ash, scoria and lava in New Zealand and Tongan islands. Proceedings 12th Pacific Science Congress, Canberra, Australia. Vol 1, abstracts of papers.

[105] Wilde R.H. 1981a. Soil map of 'Eua Island, Kingdom of Tonga. Scale 1:25,000. NZ Soil Bureau Map 199. Wellington, NZ: DSIR. https://doi.org/10.7931/zktm-yh25

[106] Wilde R. H. and Hewitt A.E. 1983. Soils of 'Eua Island, Kingdom of Tonga. NZ Soil Survey Report 68. Wellington, NZ: DSIR. 42 pp. http://doi.org/10.7931/DL1-SSR-68

[107] Wilson A.D. and Beecroft F.G. 1981. Soil map of part of Ha'apai Group, Kingdom of Tonga. Scale 1:25,000. NZ Soil Bureau Map 198. Wellington, NZ: DSIR. https://doi.org/10.7931/y4h2-dd95

[108] Wilson A.D. and Beecroft F.G. 1983. Soils of the Ha'apai Group, Kingdom of Tonga. NZ Soil Survey Report 67. Wellington, NZ: DSIR. 32 pp. http://doi.org/10.7931/DL1-SSR-67

Laboratory analyses of soil samples was undertaken by Keitha Giddens, Annette Hall and Vivienne Vortman at the NZ Soil Bureau laboratory, Taita.

Glasshouse experiments on bulk soil samples were designed to assess the plant nutrient status of 28 representative Tongan soils. In this study, Green Panic (*Panicum maximum*) was grown for four months under glasshouse conditions simulating the Tongan climate. The grass was harvested four times at three-week intervals and its response to major nutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium) and five minor nutrients was assessed using a subtractive technique.[109]

The Kingdom of Tonga Soil and Land Use Programme Seminar was held in Nuku'alofa June 14–18 1976 for Soil Bureau scientists to report the results of the soil survey and associated fertility trials, and for attendees to determine how to present results to ensure their best possible use and to decide the details of the proposed field programmes.

The seminar was opened by H.R.H. Prince Tuipelehake and chaired by Tomasi Simiki, Director MAF. The NZ Soil Resources presentation team included Gary Beecroft, Willis Burns, Les Blakemore, Mike Leamy, Gary Orbell, Bruce Miller, Wim Rijkse, John Widdowson and Hugh Wilde. The seminar was most successful and the useful discussions helped shape the final design of reports and field trials.

FIGURE 16: Field trip during the Tonga soil survey, 1976. Participants: Param Sivan, Siua Halavatau, Dr Pushjarah, Dr Goro Uehara, Charles Garnier, Alain Beaudou.[110,111]

[109] Widdowson J.P. and Blakemore L.C. 1976. Fertility of soils of Tonga. Interim Report 2. NZ Soil Bureau. Wellington, NZ: DSIR. 61 pp.

[110] Orbell G.E., Rijkse W.C. and Laffan M.D. 1981. Soil map of part Vava'u group, Kingdom of Tonga. Scale 1:25,000. NZ Soil Bureau Map 197. Wellington, NZ: DSIR. https://doi.org/10.7931/zgk5-0309

[111] Orbell G.E., Rijkse W.C., Laffan M.D. and Blakemore L.C. 1985. Soils of part of the Vava'u group, Kingdom of Tonga. NZ Soil Survey Report 66. Wellington, NZ: DSIR. 47 pp. http://doi.org/10.7931/DL1-SSR-66

Following the seminar, John Widdowson stayed in Tonga with Gary Orbell and Mike Leamy to select sites and implement field fertiliser experiments (using maize) to validate results of the glasshouse experiments.[112]

In 1983, following on from the soil surveys of the Kingdom of Tonga in 1975, NZ Soil Bureau staff involved in the surveys contributed to a non-technical booklet about the soils of the Kingdom. It was compiled by Gary Orbell and was written primarily for use in schools to promote wider understanding of Tonga's soil resources.[113]

Many scientific papers from the Tonga Soil and Land Use Programme were published.[114,115,116,117,118,119,120,121,122,123,124]

In response to the concern by the Tongan MAF that intensification for increased production of high input export crops was placing pressure on Tonga's limited soil resources, resulting in a potentially serious loss in soil productivity, a Soil Fertility and Land Evaluation Workshop was funded by the Australian International Development Assistance Bureau (AIDAB) and held in Nuku'alofa 3–7 February 1992. The workshop was chaired by Aleki Sisifa and formally opened by Hon. Baron Vaea, Minister of Agriculture and Forestry, with an address by Howard Brown, Australian High Commissioner. The workshop was attended by 45 MAF staff and the NZ Resource team, including Bruce Trangmar, Steve Smith, John Widdowson and Gary Orbell, with the MAF Resource staff involved – Haniteli Fa'anunu, Aleki Sisifa, Ofa Fakalata, Finau Pole, Viliami Manu, and Siua Halavatau.

[112] Widdowson J.P. (compiler) 1976. Proceedings of the Kingdom of Tonga Soil and Land Use Seminar, Nuku'alofa, Tonga, 14–18 June 1976. NZ Soil Bureau. Wellington, NZ: DSIR. 109 pp.

[113] Orbell G.E. (compiler) 1983. Soils of the Kingdom of Tonga – An Introduction. NZ Soil Bureau. Wellington, NZ: DSIR. 47 pp. https://tonga-psp.landcareresearch.co.nz/resources/soil-surveys-and-maps/

[114] Lee R. and Widdowson J.P. 1977. The potassium status of some representative soils from the Kingdom of Tonga. Tropical Agriculture 54: 251–263.

[115] McGaveston D.A. and Widdowson J.P. 1978. Comparison of six extracts for determining available phosphorus in soils from the Kingdom of Tonga. Tropical Agriculture 55: 141–148.

[116] Cowie J.D. 1980. Soils from andesitic tephra and their variability, Tongatapu, Kingdom of Tonga. Australian Journal of Soil Research 48: 273–284. https://doi.org/10.1071/SR9800273

[117] Hart P.B.S. and Widdowson J.P. 1981. The response of Caribbean pine, green panic, and siratro to fertilisers on soils of the 'Eua uplands, Tonga. New Zealand Journal of Experimental Agriculture 9: 255–262. https://doi.org/10.1080/03015521.1981.10425423

[118] Hart P.B.S., Widdowson J.P. and Fa'anunu H.O. 1981. Fertility evaluation of some soils in Vava'u, Tonga. NZ Soil Bureau Scientific Report 47. Wellington, NZ: DSIR. 30 pp. http ://doi.org/10.7931/DL1-SBSR-47

[119] Widdowson J.P. and Hart P.B.S. 1981. The effects of mycorrhiza on the growth of *Pinus caribbaea* seedlings in Tongan soils: preliminary investigations. NZ Soil Bureau Scientific Report 48. Wellington, NZ: DSIR. 21 pp. http://doi.org/10.7931/DL1-SBSR-48

[120] Childs C.W. and Wilson A.D. 1983. Iron oxide minerals in soils of the Ha'apai Group, Kingdom of Tonga. Australian Journal of Soil Research 21: 489–503. https://doi.org/10.1071/SR9830489

[121] Speir T.W. 1984. Urease, phosphatase and sulphatase activities of Cook Islands and Tongan soils. New Zealand Journal of Science 27: 73–79.

[122] Wilson A.D. and Giltrap D.J. 1985. Effectiveness of 'Soil Taxonomy' for prediction of soil chemical properties on Mollisols under a shifting cultivation system in the Ha'apai Group, Kingdom of Tonga. South Pacific Journal of Natural Science 7: 45–57.

[123] Widdowson J.P. and Watts H.M. 1989. Crop responses to fertiliser on some major soils in Tonga. pp. 64–80 in Haynes R.J. and Naidu R. (eds), Agricultural Development in the Pacific Islands in the 90s: Proceedings of an international conference and workshop, Suva, Fiji.

[124] Lee R., Searle P.L., Leslie D.M. and Widdowson J.P. 1989. The distribution of the major soil groups of the Cook Islands, Tonga, Niue and Fiji according to Soil Taxonomy, their chemical properties and fertility status. pp. 219–242 in Haynes R.J. and Naidu (eds), Agricultural Development in the Pacific Islands in the 90s: Proceedings of an international conference and workshop, Suva, Fiji.

An important outcome of the workshop was identification of soil management issues and future research needs to ensure sustainability of agricultural production in Tonga.[125,126,127]

The soil survey report and accompanying soil map are based on a reconnaissance survey carried out by Gibbs in 1968.[128]

Des Cowie and Pat Brophy carried out a detailed soil survey of Vaini Experimental Farm on Tongatapu and described soils along traverses across the island to determine whether more uniform mapping units could be delineated, especially in the eastern part of the island. The investigation showed that the pattern of soils in the complex mapping units of Gibbs was very variable and individual soils could only be separated out by an extremely large number of observations and at a detailed map scale. However, analyses of observations showed that predictions could be made of the range of likely soils present in any one map unit, the percentage frequency of individual soils and the dominant soil. On this basis, a decision was made to revise the soil map of Gibbs.

A Reference Manual for Understanding the Soil Resources of the Kingdom of Tonga (Leslie 2019) collated and organised the current knowledge of the Kingdom of Tonga's soils and their management. The manual describes the soil attributes significant for crop growth and matched these attributes with crop requirements, expressed in one of four classes of suitability. Based on this information, a draft report (Leslie, in press) on the crop gross margins for 35 crops was prepared.

[125] Trangmar B.B. (compiler) 1992. Proceedings of the Soil Fertility and Land Evaluation Workshop. DSIR Land Resources. Wellington, NZ: DSIR. 241 pp.

[126] Gibbs H.S. 1976a. Soils of Tongatapu, Tonga. NZ Soil Survey Report 35. Wellington, NZ: DSIR. 15 pp. http://doi.org/10.7931/DL1-SSR-35

[127] Gibbs H.S. 1976b. Soil Map of Tongatapu, Tonga. Scale 1:100,000. NZ Soil Bureau Map 81. Wellington, NZ: DSIR. https://doi.org/10.7931/hyby-mx80

[128] Cowie J.D., Searle, P.L., Widdowson J.P. and Orbell G.E. 1991. Soils of Tongatapu, Kingdom of Tonga. DSIR Land Resources Scientific Report 21. Wellington, NZ: DSIR. 55 pp. http://doi.org/10.7931/DL1-DLRSR-21

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About the Author

Dr David Leslie made a major contribution to understanding and managing soils in the five (Cook Islands, Fiji, Niue, Samoa, and Tonga) SW Pacific Islands.

His work covered 45 years of research developing soil information systems through mapping; laboratory characterisation (physical, chemical, mineralogy); spatial analysis; developing agro-technology transfer methods; and introduction of USDA Soil Taxonomy soil classification to the region.

The information assisted governments to make sound environmental, land use, planning, and land management decisions. It was however the Soil Resource Manuals, assessment of crop suitability ratings for >50 crops, crop suitability maps, and crop gross margins for each crop and country which aided growers.

The work expanded the capacity and capability of the agricultural workforce in extension activities, through training, advisory services, and advocacy.

Ancillary research followed, i.e., reviews of rural land use and developing land use policies, to ensure sustainable management of national soil resources.

Dr Leslie's research culminated in publication of 57 research papers and 22 books and scientific reports.

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