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Urease, phosphatase, and sulphatase activities of Cook Island and Tongan soils

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Abstract A study was made of the urease, phosphatase, and sulphatase activities of topsoil samples from some major islands of the Cook Islands and Tongan groups of the Southwest Pacific. The ranges of enzyme activities were wide, but generally within the limits found in temperate New Zealand soils. Two alkaline soils developed from coralline sands had lower acid phosphatase activities than had been previously found; the phosphatase in these may have had an alkaline pH optimum.

Correlation analysis showed that the relationships of enzyme activities to soil chemical and agronomic properties were generally very different for the 2 island groups. The most striking contrasts were the significant negative, and significant positive, correlations in the Cook Island and Tongan soils, respectively, of sulphatase activity with adsorbed S and with yield of green panic (*Panicum maximum* var. *trichoglume*) with all nutrients supplied except S. None of the enzyme activities was significantly correlated with organic C content in the Cook Island soils, but all were correlated significantly with it in the Tongan soil. However, strong relationships were found between urease and sulphatase activities, and between these activities and cation exchange capacity, total exchangeable cations and base saturation in the Cook Island soils, but not in the Tongan soils.

These, and other, relationships are discussed, and the possible application of soil sulphatase as an index of S nutrition in soils from Tonga is considered.

Keywords Cook Islands; Tonga; topsoils; soil enzymes; urease; phosphatase; sulphatase; soil chemistry; agronomy; green panic.

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INTRODUCTION

The intensive soil surveys of the Cook and Tongan island groups undertaken by New Zealand Soil Bureau staff in 1974 and 1975 provided an opportunity to examine the enzyme activities of some tropical Pacific Islands soils. There have been very few reports on the enzymology of tropical soils, and, apart from the investigation of invertase, amylase, and respiratory activities (Ross 1973), and of protease activity (Ladd & Jackson 1982) of soils from the New Hebrides, nothing has previously been published on the enzymology of tropical soils developed on relatively recent volcanic deposits.

In this study, urease, phosphatase, and sulphatase enzyme activities have been measured on 18 topsoils from the Cook Islands, and on 9 topsoils from 4 of the principal islands of the Kingdom of Tonga. Within each island group, enzyme activities were related by correlation analysis to soil chemical and agronomic properties. These relationships, and differences, between Cook Islands and Tongan soils are discussed.

MATERIALS AND METHODS

Location

The Cook Islands consist of 15 small islands, forming 2 groups, in the Southwest Pacific Ocean between 8 and 23°S latitude and between 156 and 167°W longitude. The soils for this study were from 5 of the 6 volcanic islands of the compact Southern Group. The climate for this group is warm and humid. For Rarotonga, the largest island, mean annual rainfall is 2012 mm and mean annual temperature 24°C, with monthly means varying from 21.5°C (August) to 25.8°C (February) (Leslie 1980). Soil parent material in the islands of the Southern Group is weathered basalt or basalt alluvium, or, on the coastal fringes, coralline sands.

The Kingdom of Tonga comprises some 150 small islands in 3 main groups in the Southwest Pacific Ocean, lying between 15 and 23°S latitude and between 173 and 177°W longitude. The soils for this study were from the principal islands of all 3 groups. The climate of the Kingdom of Tonga is also warm and humid. For Tongatapu, in the Southern Group, mean annual rainfall is 1736 mm and mean annual temperature 24°C, with monthly

Table 1 Some chemical properties of the Cook Island topsoils.

Island: Soil	Sampling depth (cm)	Moisture (%)	pH	Organic C† (%)	Total N† (%)
Rarotonga					
Tikioki heavy silt loam	0–10	57	6.3	3.9	0.29
Arorangi red clay loam	0–16	53	6.2	4.4	0.32
Matavera silty clay loam	0–20	52	6.6	5.0	0.44
Muri sandy loam	0–12	23	7.4	3.3	0.28
Poura clay loam	0–18	47	6.5	4.6	0.37
Aitutaki					
Tautu clay loam (1)	0–18	42	6.3	5.5	0.37
Tautu clay loam (2)	0–20	45	6.9	5.9	0.45
Atiu					
Te Autua clay loam	0–15	32	5.8	5.1	0.22
Te Autua clay loam (rolling phase)	0–10	33	5.9	4.4	0.19
Tetoa clay	0–15	47	6.7	5.6	0.42
Mangaia					
Rangimotia clay loam	0–15	25	6.1	4.4	0.22
Ivirua silty clay	0–22	47	5.6	3.9	0.21
Ivirua silty clay (red subsoil variant)	0–23	37	5.7	n.d.	n.d.
Keia clay loam	0–18	58	6.2	5.2	0.48
Oneroa clay loam	0–25	53	6.8	5.1	0.46
Veitatei clay	0–15	46	6.1	4.5	0.25
Mauke					
Nuata clay	0–15	35	5.9	3.4	0.16
Areora clay	0–10	54	6.0	4.8	0.36

n.d. = not determined.

†Data from Widdowson & Blakemore (1975a).

Table 2 Some chemical properties of the Tongan topsoils.

Island: Soil	Sampling depth (cm)	Moisture (%)	pH	Organic C† (%)	Total N† (%)
Tongatapu					
Vaini clay	0–30	50	6.7	3.0	0.26
Lapaha clay	0–20	45	7.2	2.9	0.23
Nuku'alofa sandy loam	0–30	44	7.4	3.4	0.32
'Eua					
Faitoka clay	0–15	66	6.6	5.7	0.76
Houma clay	0–15	54	6.1	6.1	0.37
Vava'u					
Pangaimotu clay loam	0–20	55	6.6	3.5	0.31
Longomapu clay loam	0–20	60	6.5	4.5	0.41
Tu'anekevale clay loam	0–30	40	6.4	4.1	0.38
Ha'apai					
Lifuka clay loam	0–20	38	6.8	2.1	0.23

†Data from Widdowson & Blakemore (1975b).

Table 3 Range and mean of chemical and agronomic properties of Cook Island and Tongan soils.

Property	Cook Islands†		Tonga‡	
	Range	Mean	Range	Mean
C/N	11–23	16	8–16	11
CEC (me.%)	14.0–67.0	27.1	27.8–52.1	39.3
Total exchangeable cations (me.%)§	1.9–63.8	22.4	18.9–47.8	31.6
Base saturation (%)§	13–100	59	58–92	77
0.5M H_2SO_4 soluble P (mg%)	3–421	100	3–116	34
Truog P (mg%)	0.1–26	4.5	0.5–5	1.3
Adsorbed S (ppm)	4–110	35	2–62	23
Yield of green panic¶				
No added fertiliser (%)	2–31	14	1–18	6
All nutrients except N (%)	30–104	70	14–82	46
All nutrients except P (%)	2–89	31	1–47	13
All nutrients except S (%)	2–33	18	6–46	17

†Data from Widdowson & Blakemore (1975a); no chemical analyses were performed on Ivirua red subsoil variant.

‡Data from Widdowson & Blakemore (1975b).

§Muri and Nuku'alofa soils contained free lime and, consequently were not analysed for total exchangeable cations and base saturation.

¶Results expressed as a percentage of the yield when all nutrients were supplied. All soils were tested agronomically.

means varying from 21.2°C (July and August) to 26.1°C (February) (New Zealand Meteorological Service 1970). Soil parent material for the islands of Tonga is primarily andesitic ash over coral limestone or, on the coastal fringes, coralline sands.

Soils and samples

Details of the location, parent material, description, and classification of the Cook Islands soils chosen for this study are presented by Leslie (1980), Webb (1981), Campbell (1982), Wilson (1982), and Milne (in preparation). Some information concerning the Tongan soils chosen is given in Widdowson (1976).

Bulk samples of A horizons of soils from both island groups were collected in August 1974 and were transported at ambient temperature in a field-moist condition to New Zealand. Sub-samples were taken for determination of enzyme activities and some chemical analyses, and the remainder was used for agronomic studies (Widdowson & Blakemore 1975a,b, 1976, 1977) and detailed chemical investigations for soil fertility and classification studies. The sub-samples were sieved (< 2 mm) and stored at 4°C until analysed for enzyme activities, moisture content, and pH.

Chemicals

Urea was obtained from Hopkin and Williams Ltd, Chadwell Heath, England, *p*-nitrophenyl phosphate disodium salt from BDH Chemicals Ltd, Poole, England, and *p*-nitrophenyl sulphate potassium salt from Koch-Light Laboratories, Colnbrook, England. All other reagents were analytical or laboratory grade commercial chemicals.

Analytical methods

All analytical results were calculated on the basis of oven-dry (105°C) weight of soil.

Moisture content was measured by drying overnight at 105°C, and pH in a soil-to-water suspension of 1:2.5. All other chemical analyses were conducted by the methods described in Blakemore et al. (1981).

A brief description of the samples and some chemical properties are shown in Tables 1 and 2. Table 3 shows other chemical data and the results from greenhouse pot-trials where subtractive treatments were used to assess soil fertility in the growth of the tropical grass, green panic (*Panicum maximum* var. *trichoglume*) (Widdowson & Blakemore 1975a,b).

Enzyme activities

Urease activity was determined by the automated method of Searle & Speir (1976). Phosphatase and sulphatase activities were determined according to Speir & Ross (1975), with 2 h incubations but using 0.025M *p*-nitrophenyl sulphate as the sulphatase

Table 4 Enzyme activities of Cook Island topsoils (nmol product† formed g^{-1} dry soil s^{-1}).

Soil	Urease	Phosphatase	Sulphatase
Tikioki	0.32	1.06	0.37
Arorangi	0.28	0.91	0.30
Matavera	1.08	1.54	0.85
Muri	0.15	0.23	0.12
Pouara	0.39	0.86	0.20
Tautu (1)	0.32	1.27	0.25
Tautu (2)	0.52	0.86	0.26
Te Autua	0.15	0.80	0.065
Te Autua (r.p.)	0.17	0.83	0.049
Tetoa	0.29	0.66	0.28
Rangimotia	0.25	0.59	0.050
Ivirua	0.24	0.88	0.033
Ivirua (r.s.v.)	0.088	0.41	0.020
Keia	0.89	1.48	0.62
Oneroa	0.89	0.73	0.58
Veitatei	0.50	1.38	0.20
Nuata	0.18	0.58	0.030
Areora	0.73	1.51	0.25
Coefficients of variation (%)			
Mean for all soils	6	7	14
Range for all soils	1–19	2–15	2–49

†Products: urease, NH_4-N; phosphatase and sulphatase, *p*-nitrophenol.

Table 5 Enzyme activities of Tongan topsoils (nmol product† formed g^{-1} dry soil s^{-1}).

Soil	Urease	Phosphatase	Sulphatase
Vaini	0.26	0.48	0.17
Lapaha	0.37	0.41	0.11
Nuku'alofa	0.45	0.15	0.088
Faitoka	1.84	2.17	1.02
Houma	0.31	1.92	0.42
Pangaimotu	0.33	0.54	0.37
Longomapu	0.49	1.15	0.43
Tu'anekevale	0.84	1.85	0.26
Lifuka	0.31	0.44	0.12
Coefficients of variation (%)			
Mean for all soils	10	8	8
Range for all soils	2–36	4–16	3–17

†Products: urease, NH_4-N; phosphatase and sulphatase, *p*-nitrophenol.

substrate (not 0.25M, which was reported incorrectly in Speir & Ross 1975). Three replicate assays, and 2 non-substrate controls, were used for all activities.

Correlation coefficients were determined to assess relationships between enzyme activities and other properties.

RESULTS

The enzyme activities of the Cook Island (C.I.) and Tongan (T) soils, shown in Tables 4 and 5 respectively, ranged widely (urease 0.088–1.84, phosphatase 0.15–2.17, sulphatase 0.020–1.02 nmol product formed g^{-1} dry soil s^{-1}). Ivirua red subsoil variant (C.I.) had the lowest urease and sulphatase activities and the third lowest phosphatase activity; the 2 soils containing free lime, Muri (C.I.) and Nuku'alofa (T) had the lowest phosphatase activities. Faitoka soil (T) had the highest activity of all 3 enzymes.

The correlation coefficients for enzyme activities and soil chemical and agronomic properties are given in Tables 6 and 7. For the Cook Island soils, the strongest relationship was between urease and sulphatase activities, and consequently these enzymes were generally related similarly with other properties. Urease and sulphatase activities correlated highly significantly (***, $P < 0.001$) with total N and total exchangeable cations, and correlated very significantly (**, $P < 0.01$) or significantly (*, $P < 0.05$) with several other properties. In contrast, phosphatase activity correlated very significantly or significantly with only soil moisture content, CEC, and the other enzyme activities.

For the Tongan soils, urease and sulphatase activities were again very strongly related, but the best correlations were between these 2 activities and soil total N content.

There were many differences between Cook Island and Tongan soils in the relationships of enzyme activities to soil chemical and agronomic properties (Tables 6 and 7). The most striking contrasts were the very significant negative correlations of sulphatase activity with adsorbed S and with yield of green panic in absence of S-nutrition in the Cook Island soils, compared with the significant positive correlations with these properties in the Tongan soils. In addition, whereas none of the enzyme activities was significantly related to the organic C content in the Cook Island soils, all 3 enzyme activities were correlated significantly or very significantly with this property in the Tongan soils. Also, the strong relationships found between both urease and sulphatase activities, and between these activities and CEC, total exchangeable cations and base saturation in the Cook Island soils, were not present in the Tongan soils.

Table 6 Correlation coefficients (r) for enzyme activities and properties of Cook Island soils.

Property	Degrees of freedom	Urease	Phosphatase	Sulphatase
Moisture	16	0.64**	0.68**	0.45
pH	15	0.27	0.30	0.37
Organic C	15	0.45	0.40	0.42
Total N	15	0.75***	0.39	0.80***
C/N	15	−0.63**	−0.26	−0.72**
CEC	15	0.72**	0.56*	0.86***
Total exchangeable cations	14	0.76***	0.41	0.88***
Base saturation	14	0.66**	0.27	0.78***
0.5M H_2SO_4 soluble P	15	0.25	0.23	0.34
Truog P	15	0.55*	0.25	0.59*
Adsorbed S	15	−0.39	−0.11	−0.63**
Yield of green panic				
No added fertiliser	16	0.23	0.09	0.42
All nutrients except N	16	0.10	−0.20	0.24
All nutrients except P	16	0.48*	0.30	0.60**
All nutrients except S	16	−0.45	−0.22	−0.61**
Sulphatase	16	0.90***	0.60**	—
Phosphatase	16	0.70**	—	—

*, **, *** = $P < 0.05$, 0.01, 0.001 respectively.

Table 7 Correlation coefficients (r) for enzyme activities and properties of Tongan soils.

Property	Degrees of freedom	Urease	Phosphatase	Sulphatase
Moisture	7	0.52	0.45	0.82**
pH	7	−0.27	−0.75*	−0.47
Organic C	7	0.69*	0.87**	0.76*
Total N	7	0.96***	0.75*	0.95***
C/N	7	−0.42	0.06	−0.32
CEC	7	0.38	0.16	0.45
Total exchangeable cations	6	0.41	−0.11	0.33
Base saturation	6	0.28	−0.29	0.15
0.5M H_2SO_4 soluble P	7	−0.20	−0.59	0.35
Truog P	7	−0.11	−0.42	−0.30
Adsorbed S	7	0.84**	0.86**	0.91***
Yield of green panic				
No added fertiliser	7	0.60	−0.16	0.56
All nutrients except N	7	0.08	−0.10	0.34
All nutrients except P	7	−0.17	−0.38	−0.29
All nutrients except S	7	0.55	0.70*	0.72*
Sulphatase	7	0.89**	0.75*	—
Phosphatase	7	0.78*	—	—

*, **, *** = $P < 0.05$, 0.01, 0.001 respectively.

DISCUSSION

The enzyme activities of Cook Island and Tongan soils lay generally within the ranges of values found for New Zealand topsoils (urease, 0.25–1.31; phosphatase, 0.49–5.00; sulphatase, 0.01–0.68 nmol product formed g^{-1} dry soil s^{-1}), using the same assay procedures (Speir & Ross 1975; Ross et al. 1975; Speir 1977; Lee & Speir 1979). Several Cook Island soils had lower urease activities than have been found in New Zealand soils, and 1 soil, Faitoka (T), had considerably greater urease and sulphatase activities. The alkaline soils, Muri (C.I.) and Nuku'alofa (T), developed on coralline sand, had considerably lower phosphatase activities than has been found in New Zealand soils. The dominant phosphatase in these 2 soils may have had an alkaline optimum pH, and consequently measurement of the enzyme at pH 6.5 could have underestimated its activity.

The organic C contents of these soils (Tables 1 and 2) were of the same order as New Zealand soils under pasture. Therefore the enzyme activities, when expressed on an organic C basis, would be similar to those of New Zealand soils. Ross (1973) found that amylase, but not invertase, activities of soils under forest from the New Hebrides were also similar to those of some New Zealand soils under forest, when expressed on an organic C basis.

The very large differences between the 2 island groups in the relationships of enzyme activities to other soil properties (Table 6 and 7) cannot easily be explained. However, the different parent materials of the soils (Cook Islands, basaltic; Tonga, andesitic), with concomitant differences in chemical properties and natural fertility, and different management regimes may be involved.

The absence of significant relationships between enzyme activities and organic C content, as found in the Cook Island soils, is unusual (Bremner & Mulvaney 1978; Speir & Ross 1978), although some instances have previously been noted (Speir & Ross 1978). Vegetation type may be important to this relationship in tropical soils, since Appiah (1975) found significant correlations between phosphatase activity and organic C and total N in uncultivated soils but not in the same soils growing cocoa. A precise description of the current vegetation, or vegetational history, at the sampling sites for the Cook Island (and Tongan) soils is not available; however these soils generally support a wide range of native and exotic plant species. Tongan soils appear to be more 'normal' than Cook Island soils, in that significant positive correlations of all 3 enzyme activities with organic C and total N contents, and negative relationships, albeit not usually significant, with soil pH, were found.

Because soil organic matter possesses a much greater CEC than the inorganic components of soil, on a weight for weight basis (Metson & Blakemore 1968), organic matter probably dominates the exchange complex of most topsoils with moderate to high organic C contents. Generally then, properties which correlate significantly with organic C content might be expected to be similarly related to CEC. Dalal (1975) found highly significant correlations between urease activity and both organic C content and CEC in Trinidad soils. In this present study, however, the enzyme activities of the topsoils of neither island group correlated significantly with both organic C content and CEC. This could indicate that, perhaps due to the high clay content of many Cook Island and Tongan soils, the mineral component was often the major contributor to soil CEC. In addition, for the Cook Island soils, the mineral exchange complex may be the primary locus of at least urease and sulphatase activities.

For the soils from both island groups, phosphatase activity did not correlate significantly either with the estimates of soil P status, or with any of the yield data, except the yield when all nutrients except S were supplied to the Tongan soils. Similarly, only 1 significant relationship was found between urease activity and productivity, that with yield when all nutrients except P were supplied to the Cook Island soils. Clearly, urease and phosphatase activities were not appropriate indices of N and P nutrient status respectively, in these soils.

In the Tongan soils, all 3 enzymes correlated positively and very or highly significantly with the adsorbed S content of the soil, indicating that these activities, and especially sulphatase, were good indicators of 'plant available' S. Lee & Speir (1979) also found a significant positive correlation between sulphatase and adsorbed S for temperate New Zealand soils; however, Cooper (1972) found no such relationship in Northern Nigerian soils. In the present study, the positive, significant relationship found in Tongan soils between both phosphatase and sulphatase activities and yield of green panic with all nutrients supplied except S, further emphasises the possible value of these activities as indices of S-fertility in these soils. Speir (1977) previously found that the sulphatase activities of a climosequence of New Zealand tussock-grassland soils were good indicators of ryegrass yield, in the first harvest, from pots grown at 17.5 and 22.5°C.

For the Cook Island soils only sulphatase activity correlated, very significantly, with adsorbed S and with yield when all nutrients were supplied except S. However, in marked contrast to the situation with the Tongan soils, these correlation coefficients were negative, indicating a very different relationship of sulphatase with these properties. The reason for this difference between Cook Island and Tongan soils is presently inexplicable.

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