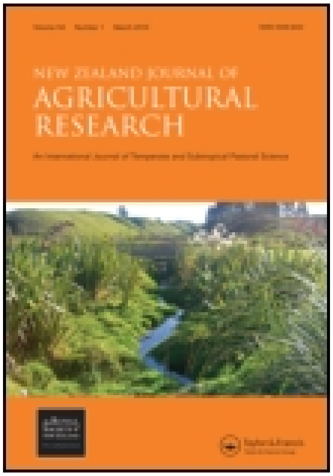

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Biochemical changes in a yellow-brown loam and a central gley soil converted from pasture to maize in the Waikato area

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Biochemical changes in a yellow-brown loam and a central gley soil converted from pasture to maize in the Waikato area

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Some biochemical properties of topsoil samples of two soils—Horotiu silt loam (yellow-brown loam) and Puniu silty clay loam (central gley soil)—in the Waikato area, that had been under pasture for at least 50 years and cropped with maize for 8 years were compared. Organic C contents of the Horotiu and Puniu pasture samples were 10.1 and 7.8 percent respectively, and total N contents 0.97 and 0.70 percent respectively. Under maize, organic C contents had declined by 40 percent in Horotiu soil and 54 percent in Puniu soil. Carbon dioxide production, net production of mineral N, microbial biomass (as measured by biomass C, mineral N flush, and ATP contents), and enzyme activities (urease, phosphatase, sulphatase, invertase, amylase, cellulase, and hemicellulase) had all declined appreciably more with cropping than had organic C contents; they would therefore provide more sensitive indicators than organic matter to changes in soil with management.

All biochemical activities (except urease and, to a lesser extent, invertase), when expressed on a soil organic C or total N basis, were lower in Horotiu than Puniu samples. Together with the organic C changes, they suggest that some stabilisation of organic matter had occurred in the allophanic Horotiu soil.

Generally, Horotiu soil that had been under maize for 11 years differed little in its biochemical activities from that under maize for 8 years.

Keywords Horotiu silt loam; Puniu silty clay loam; gley soils; allophanes; Gramineae; *Zea mays*; maize; soil micro-flora; soil composition; soil biochemical properties; organic composition; biomass; soil enzymes; pastures; crop sequence

INTRODUCTION

Maize (*Zea mays* L.) is now an important crop in New Zealand, with most of it being used for animal feeds (New Zealand Official Year Book 1980). In 1979, 27 000 hectares of land were planted in maize and yielded 230 000 tonnes of grain, an average of 8.5 t ha^{-1} (Fowler 1980); about 60 percent of this land was in the Waikato area (Buxton 1976). Because higher yields can be attained in some situations, possible factors limiting yields (Rennie 1978; Fowler 1980), including unfavourable weather (McCormick 1979, 1980), diseases (Fowler 1980), nutrient requirements (for example: Thom & Watkin 1978; Steele 1980; Steele & Cooper 1980), and soil physical properties (Cotching et al. 1979) have been considered.

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The soils studied by Cotching et al. (1979) were Horotiu silt loam (yellow-brown loam) and Puniu silty clay loam (central gley soil), with their clay minerals being predominantly allophane and halloysite respectively (Cotching 1978). With continuous maize cropping, soil physical changes had reached a steady state in Horotiu soil after 3 years; in Puniu soil, changes continued and after 6 years it was considered to be in poor physical condition (Cotching et al. 1979). Because of their different physical characteristics, these two soils were selected for the biochemical study reported here. The properties examined were organic matter content, three biochemical indices of microbial biomass, and respiratory, nitrogen-mineralising, and enzyme activities. The enzymes investigated were those involved in the hydrolytic decomposition of carbohydrates, and in the mineralisation of organic nitrogen, phosphorus, and sulphur compounds.

The main objectives of this study were to compare the levels of these biochemical properties in (1) soil under maize and under adjacent pastures, (2) the allophanic Horotiu and non-allophanic Puniu soil, and (3) Horotiu soil that had been under maize for a different number of years. Inter-relationships between these properties were also assessed to further the understanding of the extent to which the properties can be differentially influenced by land management practices.

MATERIALS AND METHODS

Sites

The sites were some of those used by Cotching et al. (1979), and the same numbering is used here. Mean annual temperature at both sites was 12.8–13.9°C; annual rainfall was 1250 mm at the Horotiu pasture site and 2000 mm at the Puniu site (Cotching 1978). At the time of sampling (5 April 1979), the two cultivated Horotiu sites (H3 and H4) had been under maize for 8 and 11 years respectively, whereas the Puniu site (P4) had been under maize for 8 years. The adjacent reference sites for both soils (H1 and P1) had been under pasture for at least 50 years.

Both pasture sites had received regular applications of potassic superphosphate (Cotching 1978). The maize fields had been cultivated to a depth of 18–20 cm, and treated with mixed fertilisers, including various N fertilisers at the Horotiu H3 site and ammophos at the other two sites (Cotching 1978). The herbicide atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine) had been used on all three maize sites. The Horotiu H3 site had also been treated with alachlor (2′-chloro-2, 6-diethyl-N-methoxymethylacetanilide) and the Puniu P4 site with "eradicane" (EPTC(S-ethyl-dipropylthiocarbamate) + N,N-diallyl-dichloracetamide) (Cotching 1978). After harvesting, the maize stubble in all three maize sites was grazed by cattle (Cotching 1978).

Weeds were almost absent from the Puniu maize site. Grass weeds occurred sparsely at the Horotiu H3 site, and were prevalent at the H4 site; they were avoided when sampling.

The exact location of the sites, and further site and management details are given by Cotching (1978).

Soils and sampling

Horotiu silt loam has been formed from alluvial deposits of volcanic debris on the Waikato River fan (Cotching et al. 1979). Puniu silty clay loam has developed on alluvial terraces of the Waipa River. The clay (<2 μm) contents of topsoil (0–5 cm deep) samples taken in December 1976 from the above sites ranged from 10 to 19% for Horotiu soil, and from 42 to 45% for Puniu soil (Cotching 1978).

All samples were taken in triplicate from each site on 5 April 1979, and each sample comprised 30 cores (2.5 cm diam; 0–5 cm deep).

At the time of sampling, the maize crops were mature but unharvested. The areas sampled were at least 30 m distant from boundaries; they comprised only a small proportion of the total area under maize. All cores were taken within rows, in gaps between plants where seeds had failed to germinate. For each sample, 10 cores were collected at about 10 m intervals from each of three different rows; the rows selected were themselves about 15 m apart.

The pasture samples from the Horotiu site were taken from the slight elevations present throughout the area. Those from the Puniu site were taken at regular intervals over the entire area.

Samples were sieved (<2 mm) on 6 April, and stored at 4°C. All biochemical determinations commenced within the next 4 days.

Analytical methods

Unless stated otherwise, results are reported on an oven-dry (105°C) weight of soil basis. The significance of differences between (a) pasture and the corresponding maize samples, (b) Horotiu and Puniu

TABLE 1 — Some properties of the soil samples. The significance of differences between samples taken under pasture and maize is indicated by *, **, ***; degrees of freedom, 4.

Soil	Vegetation (Site no.)	Moisture (%)	pH	Organic C (%)	Total N (%)	C/N	CO_2 production (pmol per gram dry soil per sec)	Min-N production over 0–14 days ($\mu g.g^{-1}$ dry soil)
Horotiu	Pasture (H1)	68	6.3	10.1	0.97	10.3	72	67
	Maize (H3)	52**	6.3†	6.0***	0.53***	11.4*†	17***	12***
	Maize (H4)	47***	5.4***†	5.8***	0.58***	10.0†	16***	13***
Puniu	Pasture (P1)	43	5.8	7.8	0.70	11.2	98	60
	Maize (P4)	32***	6.4**	3.6***	0.30***	11.8	21***	17***
Coefficients of variation (%):								
(a) Mean for all soils		4	1	4	4	3	6	14
(b) Range for all soils		2–8	1–2	1–6	2–7	2–4	0–13	9–21

†Significant differences ($P<0.05$) between the Horotiu H3 and H4 samples.

pasture samples, and (c) the two sets of Horotiu maize samples, was determined by Student's *t* test. Relationships between properties were assessed by the use of correlation coefficients.

Moisture, organic C and total N contents, and pH (in water) were determined according to Blakemore et al. (1977).

Carbon dioxide production.

Carbon dioxide (CO_2) production was determined at 25°C with 20 g soil at 60% water-holding capacity in Biometer flasks (Bartha & Pramer 1965). The incubation period selected was that which gave the most constant rate of CO_2 production; it was 7–20 days for the Puniu pasture samples and 13–20 days for the other samples.

Soil nitrogen (N) mineralisation.

Net mineralisation of soil N at 25°C was measured according to Ross (1974). Min-N (= ammonium-N + nitrate-N (NO_3-N)) in 2*M* KCL extracts was determined by Autoanalyser procedures (Ross et al. 1979). Incubation periods ranged from 14 to 56 days.

Biomass C.

Measurements of biomass C were made by the chloroform fumigation procedure (Jenkinson & Powlson 1976), as described by Ross et al. (1980). The incubation periods selected for measuring CO_2 production varied from 0–7 to 0–10 days for the fumigated samples, and from 7–20 to 13–20 days for the unfumigated samples.

Mineral N flush.

Soil was taken from the same fumigated and unfumigated samples as those used for the biomass C measurements. The samples were incubated for 14 days at 60% water-holding capacity at 25°C. The difference between the net amount of Min-N produced by the fumigated and unfumigated samples was taken to be the Min-N flush (Ayanaba et al. 1976; Ross et al. 1980).

ATP.

ATP was determined essentially by the procedure of Jenkinson & Oades (1979), as described by Ross et al. (1980).

Enzyme activities.

All enzyme activities were determined at 30°C in buffers as follows:

invertase and amylase: acetate-phosphate (pH 5.5) (Ross 1978);

cellulase: acetate (pH 5.0), with sodium carboxymethylcellulose (No. C-8758; Sigma Chemical Co., St. Louis, Mo., U.S.A.) as substrate (Ross & Speir 1979);

xylanase: phosphate (pH 6.8), with larchwood xylan (Sigma) as substrate (Speir & Ross 1981a);

urease: phosphate (pH 6.8) (Speir & Ross 1981a);

phosphatase: modified universal buffer (pH 6.5) (Speir & Ross 1981a);

sulphatase: acetate (pH 5.9) (Speir & Ross 1981a).

Invertase and amylase assays were carried out as single determinations on each replicate sample. The other enzyme assays were carried out in duplicate on each sample, with one non-substrate control.

RESULTS

Soil chemical properties

According to the criteria of Blakemore et al. (1977), the samples were slightly–moderately acid. Organic carbon contents were medium (with only one exception), and total N contents either medium or high; they were significantly higher ($P<0.01$) in the Horotiu than in the corresponding Puniu samples. All C:N ratios were low.

Except for pH, the values of these properties were significantly lower in the maize than in the corresponding pasture samples (Table 1). In the Horotiu H3 and H4 maize samples, only pH and C:N ratios differed significantly.

CO_2 production

CO_2 production was significantly higher ($P<0.05$) in the Puniu than in the corresponding Horotiu samples (Table 1).

Mineral N production

All non-incubated samples contained appreciable amounts of Min-N (Fig. 1). Min-N contents were, however, lower ($P<0.05$) in the maize than in the corresponding pasture samples, and higher ($P<0.01$) in the Horotiu than in the Puniu pasture samples; differences between the maize samples were less distinct. In the non-incubated Puniu pasture samples, 77% of the Min-N was present as NO_3-N; in the other samples, an average of 95% was present as NO_3-N.

Net Min-N production over 14 days was similar in the corresponding samples of both soils (Table 1). On subsequent incubation, the rate of Min-N production in the Horotiu pasture samples remained essentially the same, whereas it increased appreciably in the Puniu pasture samples (Fig. 1). In the incubated samples, with only one minor exception, an average of 98% of the Min-N was present as NO_3-N. Over all incubation periods, Min-N production was significantly lower ($P<0.01$) in the maize than in the corresponding pasture samples. None of the differences in Min-N production by the Horotiu H3 and H4 maize samples was significant (Fig. 1).

Net Min-N production, as a percentage of total soil N, was significantly greater ($P<0.01$) at all incubation times in the Puniu than in the corresponding Horotiu samples (Table 2).

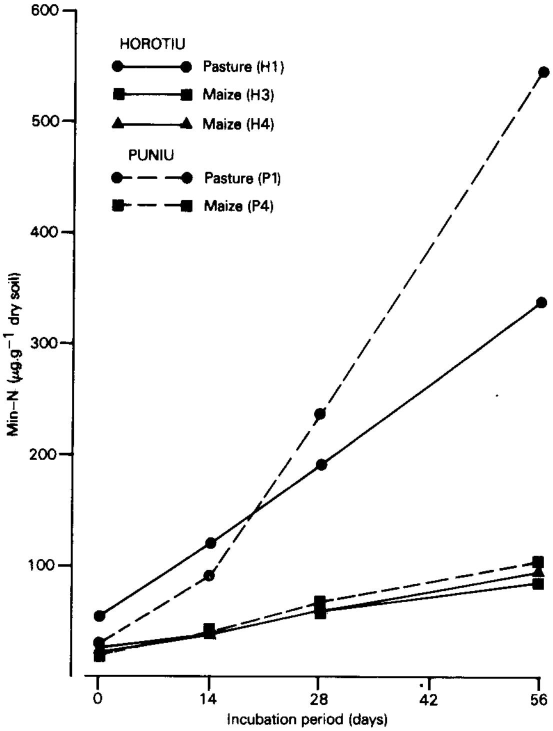

Fig. 1 — Min-N content of samples incubated at 60 percent water-holding capacity at 25°C.

TABLE 2 — Percentage of total N mineralised on incubation of soil at 60 percent water-holding capacity at 25°C. The significance of differences between samples taken under pasture and maize is indicated by *, **, ***; degrees of freedom, 4.

Soil	Vegetation (Site no.)	Incubation period (days) 0–14	0–28	0–56
Horotiu	Pasture (H1)	0.7	1.4	2.9
	Maize (H3)	0.2**	0.6***	1.1***
	Maize (H4)	0.2**	0.6***	1.2***
Puniu	Pasture (P1)	0.9	3.0	7.4
	Maize (P4)	0.6*	1.6**	2.8***
Coefficients of variation (%):				
(a) Mean for all soils		18	6	8
(b) Range for all soils		9–25	2–10	5–17

Microbial biomass

As shown by the coefficients of variation (Table 3), the biochemical indices of microbial biomass were somewhat more variable than the chemical properties (Table 1), with ATP content varying most.

All three indices of microbial biomass, and also biomass C and Min-N flush values as a percentage of soil organic C and total N respectively, were significantly lower in the maize than in the corresponding pasture samples (Table 3). Both Min-N flush and ATP content were higher ($P<0.05$) in the Puniu than in the Horotiu pasture samples, but biomass C content did not differ significantly between them. All three indices were also higher (some significantly) in the Puniu than in the Horotiu maize samples.

Biomass C and Min-N flush values, and percentages of biomass C/organic C and Min-N flush/total N, were all significantly higher ($P<0.05$) in the Horotiu H3 than in the H4 maize samples; (the difference between the two ATP values was not significant).

Enzyme activities

All enzyme activities were significantly lower in the maize than in the corresponding pasture samples (Table 4). Generally, replicate variability of enzyme activities was similar to that of the microbial biomass values (Table 3).

In contrast to CO_2 production and the other biochemical properties (Fig. 1, Tables 2 and 3), enzyme activities were not invariably higher in the Puniu than in the Horotiu pasture samples. Notable exceptions were invertase and urease activities, which were considerably higher ($P<0.01$) in the Horotiu than in the Puniu samples. Amylase activity was also slightly higher ($P<0.05$) in the Horotiu samples, and sulphatase activity was similar in both sets of pasture samples. Only cellulase, xylanase, and phosphatase activities were significantly higher ($P<0.05$) in the Puniu than in the Horotiu samples.

Generally, the enzyme activities were either greater in the Puniu than in the Horotiu maize samples, or not significantly different. The main exception was urease activity which was significantly lower ($P<0.05$) in Puniu than in both Horotiu samples.

Differences between the Horotiu H3 and H4 maize samples were not consistent and were mostly non-significant. However, invertase and sulphatase activities were significantly higher ($P<0.05$), and xylanase activity lower, in the H3 than in the H4 samples.

Relations between soil properties

CO_2 and net Min-N production, and the biochemical indices of microbial biomass, were all correlated significantly ($P<0.01$; except for ATP and total N content ($P<0.05$)) with soil organic C and total N contents, but even more significantly ($P<0.001$) with each other.

Each enzyme activity was also correlated significantly with the above properties, but the degrees of relationship varied considerably (Table 5). For example, urease activity was correlated more significantly with soil organic C content than was cellulase activity. With only two exceptions, all enzyme ac-

TABLE 3 — Biomass C, Min-N flush, and ATP contents. The significance of differences between samples taken under pasture and maize is indicated by *, **, ***; degrees of freedom, 4.

Soil	Vegetation (Site no.)	Biomass C ($\mu g.g^{-1}$ soil)	Min-N flush ($\mu g.g^{-1}$ soil)	ATP ($\mu g.g^{-1}$ soil)	Biomass C / Organic C %	Min-N flush / Total N %
Horotiu	Pasture (H1)	2170	238	12.8	2.2	2.5
	Maize (H3)	590***†	49***†	3.4***	1.0***†	1.0***†
	Maize (H4)	390***†	35***†	4.2***	0.7***†	0.7***†
Puniu	Pasture (P1)	2540	310	18.4	3.3	4.4
	Maize (P4)	620**	63***	4.8***	1.7**	2.1***
Coefficients of variation (%):						
(a) Mean for all soils		8	7	11	8	8
(b) Range for all soils		3–15	5–9	7–14	3–14	6–10

†Significant differences ($P<0.05$) between the Horotiu H3 and H4 samples.

TABLE 4 — Enzyme activities calculated on the basis of pmol products formed per gram dry soil per sec. The significance of differences between samples taken under pasture and maize is indicated by *, **, ***; degrees of freedom, 4.

Soil	Vegetation (Site no.)	Invertase‡ ('glucose' formed)	Amylase ('glucose' formed)	Cellulase ('glucose' formed)	Xylanase ('xylose' formed	Urease (ammonium-N formed)	Phosphatase ('p-nitrophenol' formed)	Sulphatase ('p-nitro-phenol' formed)
Horotiu	Pasture (H1)	3000	430	72	290	2140	3120	1380
	Maize (H3)	670***†	96***	33***	110***†	410***	830***	290***
	Maize (H4)	500***†	75***	37***	140***†	420***	910***	210***
Puniu	Pasture (P1)	1460	390	130	410	1460	5570	1230
	Maize (P4)	640***	110***	34***	140***	270***	1050***	240***
Coefficients of variation (%):								
(a) Mean for all soils		11	9	8	9	9	6	5
(b) Range for all soils		8–14	3–14	4–15	6–10	2–14	4–8	1–11

†Significant differences ($P<0.05$) between the Horotiu H3 and H4 samples.

TABLE 5 — Correlation coefficients for enzyme activities and soil properties. Degrees of freedom, 13.

Source of variation	Invertase	Amylase	Cellulase	Xylanase	Urease	Phosphatase	Sulphatase
Organic C	0.89***	0.86***	0.60*	0.68**	0.94***	0.62*	0.88***
Total N	0.88***	0.81***	0.54*	0.63*	0.92***	0.56*	0.84***
CO_2 production	0.70**	0.94***	0.96***	0.99***	0.85***	0.98***	0.94***
Min-N production	0.89***	0.99***	0.82***	0.90***	0.95***	0.87***	0.99***
Biomass C	0.77***	0.97***	0.91***	0.96***	0.90***	0.94***	0.96***
Min-N flush	0.73**	0.95***	0.94***	0.96***	0.85***	0.97***	0.95***
ATP	0.64*	0.91***	0.97***	0.99***	0.81***	0.98***	0.90***
Invertase		0.89**	0.49 (*)	0.62*	0.95***	0.56*	0.89***
Amylase			0.83***	0.90***	0.96***	0.87***	0.99***
Cellulase				0.98***	0.70**	0.99***	0.83***
Xylanase					0.80***	0.98***	0.90***
Urease						0.73**	0.97***
Phosphatase							0.86***

tivities were correlated more significantly with CO_2 and Min-N production values than with soil organic C or total N contents. Correlation coefficients for enzyme activities and microbial biomass indices were also high; exceptions were invertase, and to a lesser extent, urease.

Generally, the enzyme activities were correlated highly with each other. The main exception was again invertase (with cellulase, xylanase, and phosphatase activities).

DISCUSSION

The decline in organic matter content in these topsoils with continuous maize cropping would have resulted partly from ploughing and cultivation and partly from decomposition. Although the extent to which ploughing and seed-bed preparation contributed to this decline cannot be accurately assessed, it is clear from the organic C contents of pasture and maize samples from 0–5 and 6–16 cm depths (Cotching 1978) that soil mixing alone was not responsible. It is also apparent from the data of Cotching (1978) that any of the differences in soil dry bulk density that resulted from continuous cultivation could not explain the marked decline in organic matter content or values of soil biochemical properties.

In Horotiu soil at 0–5 cm depth, the organic C content had declined by 40 and 43 percent after 8 and 11 years' continuous cropping respectively; in Puniu soil it had declined by 54 percent after 8 years' cropping. These were almost identical to the changes observed by Cotching (1978) after 6 years' cultivation. As suggested by Cotching (1978), the organic C content in Horotiu soil appears to have reached a relatively steady state after 6 years. Although a steady state was not observed in Puniu soil after 6 years' cropping, our data suggest that the rate of decline of organic matter in this soil would have subsequently ceased or slowed down appreciably.

With the cropping of both soils, the values of all biochemical properties, including the indices of microbial biomass and enzyme activities, had declined appreciably more than had organic C contents. Powlson & Jenkinson (1979) also found that microbial biomass responded to soil management changes more quickly than did soil total C or N contents. They considered that biomass measurements could give early warning of soil changes long before changes in total C or N became measurable. Our study confirms their conclusion, and suggests that other biochemical parameters could also be used as early indicators of the effects of management changes in soil. The degree to which such changes could take place and yet still be compatible with satisfactory plant productivity can only be decided by detailed trials with specific soils and crops.

Major factors causing biochemical differences between the soils under maize and pasture would be cultivation, and the consequent loss of organic matter, and subsequent differences in vegetative cover and root production. Fertilisers, herbicides, and the intensity of cattle grazing of the maize stubble may also have had some influence in establishing the levels of biochemical activities of the soils under maize. Relations between crop management and soil biochemical activities can, however, be complex (Speir & Ross 1978), and more detailed trials would be necessary to assess the influence of any particular management practice on these biochemical properties.

The values of all biochemical properties, when expressed on an organic C basis, were lower in Horotiu than in the corresponding Puniu samples. The only exceptions were invertase activity, which was higher in the Horotiu than in the Puniu pasture samples, and urease activity which was higher in all Horotiu than in the corresponding Puniu samples. These results, in conjunction with the higher levels of organic C in the Horotiu than in the Puniu samples under maize, suggest that the allophanic Horotiu soil contained a relatively high proportion of stabilised organic matter. Although differences in annual rainfall and management practices between the Horotiu and Puniu sites may have contributed somewhat to these differences in organic matter content, the nature of the predominant clay minerals is likely to have been chiefly responsible. Stabilisation would not have resulted from clay content, which was appreciably lower in Horotiu than in Puniu soil (Cotching 1978), but from the presence of allophane in the Horotiu soil. In studies of other yellow-brown loams with high allophane contents, Broadbent et al. (1964) concluded that allophanic soils contain a stable clay-organic matter complex, which is formed relatively slowly. They speculated that fresh plant remains might, in contrast, be little affected by allophane because they have few reactive groups capable of forming stable complexes with metals. Appreciable biochemical activities associated with the decomposition of these remains could therefore occur, as shown by Broadbent et al. (1964), and as suggested by this present study.

Although the percentages of biomass C/total C were all lower in the Horotiu than in the corresponding Puniu samples, the actual value of 2.2 in the Horotiu pasture samples was indicative of an appreciable microbial population, and was comparable to the values of 1.5–2.8 percent found for some other non-allophanic soils under pasture (Ross, unpublished data). The values of 1.0 and 0.7 for percentage of biomass C/total C in Horotiu soil under maize were, however, lower than the values of about 1.7–2.0 found for Puniu soil under maize, and for some Nigerian, English, and Australian soils under crops (Ayanaba et al. 1976; Jenkinson & Powlson 1976; Amato & Ladd 1980). Time of sampling, which can influence biomass C/total C ratios in soils under crops (Lynch & Panting 1980), was here identical for both Horotiu and Puniu soils. It is, however, possible that differences in management practice had some influence on the ratios, as shown elsewhere (Ayanaba et al. 1976; Lynch & Panting 1980), even though differences in the clay mineral composition of the Horotiu and Puniu soils are likely to have had the greatest effect.

The higher content of microbial biomass, as indicated by biomass C and Min-N flush values, in

Horotiu soil that had been cropped for 8 (H3 samples) rather than 11 (H4 samples) years, might suggest that biochemical activities had declined further over the 3-year period. Other results did not follow this trend, and it generally appears that biochemical activities did not decline consistently between 8 and 11 years' cropping. From the values of CO_2 and Min-N production, and ATP contents, it may be assumed that microbial biomass in the H3 samples was proportionately less active metabolically than was that in the H4 samples.

In these pasture and maize samples, the three indices of microbial biomass did not all vary in the same way, with the ratios of biomass C:Min-N flush, biomass C:ATP, and Min-N flush:ATP ranging from 8.3 to 12.0, 94 to 174, and 8.3 to 18.7 respectively (calculated from data in Table 3). These rather variable ratios confirm previous results with soils from tussock grasslands (Ross et al. 1980) in showing that the ratios were not always constant in New Zealand soils. Previously Ayanaba et al. (1976), Jenkinson et al. (1979) and Oades & Jenkinson (1979), had suggested, on the basis of studies with some Nigerian, Australian, and English soils, that the ratios were usually relatively constant and that biomass C could be estimated from Min-N flush or ATP values by the use of constant conversion factors.

Levels of enzyme activities were, to some extent, associated with organic C contents, as found with other cropping soils (for example, by Doran (1978) and Klein & Koths (1980)). The correlation data show, however, that the relationships between activities of the various enzymes and soil organic C contents could vary considerably. Clearly, additional factors are involved in the establishment of the levels of these enzymes at the different sites. This is emphasised by the correlation data (Table 6) which, in spite of the significant relationships between most of the biochemical properties, show that not all enzyme activities were inter-related to the same extent.

We do not know why urease, and to a lesser extent invertase, activities were higher, on an organic C basis, in the Horotiu than in the corresponding Puniu samples, in contrast to the other five enzymes. It is of interest, however, that the activities of urease and invertase in a very different environment (tussock litter at an alpine site) also showed different characteristics from the other five enzymes; in that environment, they appeared to be favoured by comparatively dry rather than moist conditions (Speir & Ross 1981b). Possible differences in animal stocking rates during the grazing of pastures or maize stubble, and the amounts of urea excreted, are unlikely to have directly influenced soil urease values. Zantua & Bremner (1976) found that treatment of soils with urea had no direct effect on urease activity; previous results of the influence of urea on soil urease activity were considered to be inconclusive (Bremner & Mulvaney 1978).

Although plant remains, microbial cells, and free and stabilised enzymes can all contribute to the overall enzyme activities of soil (Burns 1978; Ladd 1978; Skujins 1978), we have no data to assess the relative contribution of these sources in the Horotiu and Puniu soils. Whereas any of the enzyme activities could provide a general indication of the overall biochemical activities of the soils under pasture and maize, it is apparent from their relative variability in the different samples that such an indication would be in very broad terms only. Crop yield data (which were unavailable in this study) are required to estimate whether any of the changes in enzyme activities with continued cropping are closely related to changes in yields. Judged by other studies (Ross, unpublished data), some close relationships are possible, but not invariably found (Skujins 1978). Although the quantitative role of enzymes in the metabolism of organic compounds in soils has generally still to be established, the possibility does exist that changes in crop yields are partly the result of accompanying changes in soil enzyme activities and concomitant mineralisation rates (Klein & Koths 1980).

CONCLUSIONS

Organic matter contents, microbial biomass, and other biochemical activities were all appreciably lower in the soils that had been cropped to maize for 8 years than in the corresponding soils under pasture. Generally, microbial biomass and biochemical activities had declined more than had organic matter content, and they would provide a more sensitive index of management changes in soil.

The percentage decline of organic C was lower in Horotiu than in the Puniu samples. When expressed on an organic C or total N basis, the indices of microbial biomass, CO_2 and net Min-N production values, and enzyme activities (with the exception of urease and, to a lesser extent, invertase) were also lower in the Horotiu than in the corresponding Puniu samples. Some stabilisation of organic matter in the allophanic Horotiu soil is therefore suggested.

In Horotiu soil under maize, organic matter content and biochemical activities had generally not declined further between 8 and 11 years' cropping.

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