Biological and biochemical quality of pastoral soils: spatial and temporal variability

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Abstract

This paper reports results of the first year of soil biochemical and microbiological monitoring programme carried out to establish "normal" ranges of values for these soil attributes. Study was conducted on 24 farm sites on yellow-brown loam soils around the Waikato area. Twelve dairy farms and a similar number of sheep–beef farms were selected on the basis of high productivity. Soil samples (0–75 mm depth) were collected at 3-monthly intervals and the following measurements were carried out: soil microbial- C, N, S and P, CO_2 evolution, substrate-induced respiration, anaerobic mineralisable N, dehydrogenase activity, fluorescein diacetate (FDA) hydrolysis, amounts of soluble-C and N, extractable NO_3 and NH_4, soil pH, Olsen P, KH_2PO_4 extractable SO_4-S and organic S, and hydraulic conductivity. Climatic data, records of fertiliser and other additives and productivity were also collected to interpret the variations in these properties. Variables measured from the Horotiu and Tirau silt loam soils showed considerable similarity, however, Otorohanga soils had significantly higher amounts of total and extractable soil C and N. As expected, being a higher input system, soil nutrient status (P, SO_4, NO_3 and NH_4) on dairy farms was generally higher than the sheep–beef farms. The most significant difference was for the Olsen P values, which were about 60–70% higher under dairying. Soil pH on dairy farms was significantly higher than sheep–beef farms. However, total C and N values were significantly higher under sheep–beef than dairy farms. Similarly, the amounts of mineralisable N in all seasons were much higher for the sheep–beef than dairy farms. Apart from total microbial S, none of the other microbial biomass measurements showed any significant effect of season or difference among the soil types. This lack of seasonal effect on microbial biomass can be attributed to the unusual mild seasonal variation during the study. For the various microbial biomass measurements, sheep–beef farms generally had significantly higher values than dairy farms. Microbial C, N, SO_4 and total S values were significantly higher for sheep–beef than dairying. The ratios between soil C, N to microbial C, N and microbial C:N showed no consistent pattern between the farm types.

Keywords: C and N, enzyme activity, microbial biomass, seasonal variations, soil fertility

Introduction

It is of vital importance that soils are managed to ensure sustained and continued productivity for generations to come. Retention or improvement of present soil quality status is therefore crucial. The Ministry for the Environment and regional councils have legislative responsibility to ensure that environmental quality (land, water and air) is not compromised during primary production. Besides these authorities, farmers are interested also in maintaining soil quality to protect the productive soil base; therefore they want more scientific information about the effects of specific on-farm management systems on soil quality attributes. However, no sensitive soil tests are available to foretell if a particular management practice will adversely affect soil quality.

There is growing evidence that soil microbiological and biochemical properties have potential to be sensitive indicators of soil ecological stability, stress and restoration. Turco *et al.* (1994) have indicated that measurements of soil microbial biomass and its activity can be a useful quantitative bioindicator of soil quality because microbes play a vital role in the decomposition of plant and animal materials, mineralisation and immobilisation of nutrients, decomposition of organics, biogeochemical cycling such as N_2 fixation, and formation of macro-aggregation for favourable soil water retention and air flow. Being at the top of the decomposer food web, any adverse effect on a given soil ecosystem will initially disturb soil microbial communities; therefore monitoring microbial biomass and changes in its microbial diversity and activity could be a sensitive tool in determining soil quality status. However, one of the main problems in using these properties as indicators of soil quality is the lack of calibration, interpretation and understanding of the norms and ranges of these measurements in a soil

group–type under a given management regime. As a first step towards a quantitative understanding of these parameters, a long-term field study has been initiated to determine norms of these values in major soil groups under pastoral agriculture. The main thrust of this study is to quantify seasonal and spatial variations associated with soil biochemical and microbial properties. In this paper, we report some of our findings after the first year of the study.

Materials and Methods

Site selection

Sites were selected from a yellow-brown loam soil group located in the Waikato region. Three soil types dominate this soil group: Horotiu, Otorohanga and Tirau silt loams. Therefore for determining the spatial variability within soil type, four dairy farms and four sheep–beef farms from each soil type were selected. Production criteria were also considered in the site selection process. Dairy farms were chosen on the basis of their milkfat production levels (above 500 kg/ha/yr) and soil Olsen P values (above 30 mg/kg soil). Sheep–beef farms were chosen on the basis of stock unit carrying capacity (above 15 stock unit/ha) and Olsen P values greater than 15 mg/kg soil. At each site, a paddock representative of the overall productivity of the farm was chosen for monitoring soil microbial and biochemical properties.

Sampling

Soil samples were collected at 3-monthly intervals coinciding with seasons (spring, summer, autumn and winter). Sixty cores (7.5 × 2.5 cm) were collected at each sampling from a transect of 100 × 6 m^2, which were pegged in the direction of slope. Cores were bulked together and sieved fresh through a 4 mm sieve. Coarse roots and plant residues that passed through the sieve were discarded from the samples. After sieving, each sample was sub-divided into three, the first part was air dried, the second part was stored at 4°C and the third was analysed as fresh. Here we report the results from the fresh sample analysis.

Measurements

Physical

The soil moisture content of the samples was determined by the gravimetric method. Saturated hydraulic conductivity was measured using intact cores (5 cm depth × 10 cm diameter).

Chemical and biochemical

Soil pH in fresh samples (1:2.5 soil to water ratio) was measured by glass electrode using Mettler DL-25 pH meter. Olsen P (sodium bicarbonate extractable P) was determined by the method of Olsen *et al.* (1954). Amounts of KH_2PO_4 extractable SO_4-S and organic S in soils were determined following the method of Watkinson & Perrott (1990). Total C and N was determined by high temperature combustion using a Leco Furnace. The easily available pool of C and N was extracted with 0.5 M K_2SO_4 solution (see later). Anaerobic mineralisable N was measured by the method of Keeney & Bremner (1966). Amounts of N mineralised as ΔNH_4^+-N after 7 days of incubation at 40°C were measured by injecting 1 ml of the extractant into Tecator 5010 flow injection analyser.

Microbial biomass and microbial activity

Microbial biomass C was measured by a modified fumigation extraction method of Vance *et al.* (1987). Triplicate samples (5 g dry wt.) were fumigated with chloroform. Fumigated and corresponding non-fumigated (5 g dry wt., triplicate) subsamples were then extracted with 0.5 M K_2SO_4 (1:5 soil:solution ratio) for 2 h on an end-over-end shaker at 40 rpm and 20°C. Suspended samples were centrifuged for 5 min at 3500 rpm and filtered through Whatman 42 filter paper. Amounts of C in these extracts were determined as described by Wardle & Ghani (1995). Microbial N was also measured in the same extracts as suggested by Brooks *et al.* (1985). Microbial S was measured as described by Ghani *et al.* (1993). The amounts of sulphate in the fumigated and non-fumigated samples were determined by HPIC method of Watkinson & Perrott (1990). Microbial P was measured by a method suggested by Sarathchandra *et al.* (1984).

Basal respiration, as described by Wardle (1993), was measured by placing subsamples (15 g oven-dry weight of soil) in 169 ml air-tight containers which were kept at 22°C. The total CO_2-C released into the head space over a 3 h period, beginning after 1 h of stabilisation, was assessed by injecting 1 ml subsamples into an infrared gas analyser. Substrate-induced respiration (Anderson & Domsch 1978) was determined as for basal respiration but with an amendment of the sample with 75 mg glucose. The values obtained from this measurement were assumed to be proportionally related to the glucose-responsive component of the microbial biomass.

Enzyme activity

Fluorescein diacetate (FDA) hydrolysis rate was measured by a modified method of Schnurer & Rosswall (1982). Tubes containing 1 g (dry wt.) of soil and 60 mM phosphate buffer (total liquid volume 4 ml) were mixed with FDA (final concentration, 10 µg/ml or 40 µg ml/g soil). Tubes were incubated for 1 h on a rotary

shaker at 25°C. The reaction was stopped by adding 4 ml of pre-cooled (4°C) acetone, centrifuged the tubes at 1300 g for 5 min. The clear supernatant was removed and the absorbance read at 490 nm.

Soil dehydrogenase activity was determined by a modification of the method of Benfield *et al.* (1977) using the substrate 2-*p*-iodophenyl-3-*p*-nitrophenyl-5-phenyl tetrazolium chloride (INTF). Field moist soil (5 g dry wt. equivalent) and substrate was incubated at 30°C for 24 h. After extraction with the solvent, the end product (INTF, made up in the solvent, 1:1.5 tetrachloroethylene:acetone) was estimated by reference to a set of standards. Appropriate corrections were made for the retention of INTF by soils and absorbance readings were also corrected for blanks. Values are expressed as μg of INTF released/g soil/h.

Results and discussion

Seasonal variations

Saturated hydraulic conductivity which is a function of macroporosity and soil structure, was a highly variable soil physical property as evident from the high SED values (Table 1). However, the values indicate that soil water movement in the top surface among these soils is towards the higher end of the scale. Nevertheless, because of the high variability, this measurement is not deemed a suitable indicator of soil quality in the pastoral ecosystem. Gravimeteric moisture content measurements showed that Otorohanga silt loam had a significantly higher moisture than the Horotiu or Tirau silt loam. The summer of 1995–96 was a relatively wet summer; therefore there was no apparent water deficiency shown in any of the sampling periods. Among the chemical measurements, values of variables such as Olsen P, SO_4-S, extractable N, NO_3, NH_4-N and pH are affected by additions of fertilisers and lime and therefore these variation in soil properties cannot be interpreted as a function of seasonality alone. Values of these variables can be used only for a better understanding of inputs and outputs rather than as soil quality measurement. There was some indication of lowering in pH values from spring to autumn. The extractable carbon and anaerobically mineralisable N were significantly ($P<0.01$) higher in summer in all soils. Among all the soil types, the Otorohanga soil had significantly ($P<0.01$) higher values of these variables than the other two soils. These differences could be related to the differences in the amounts and quality of organic matter. This soil also contained significantly higher amounts of total C and total N (Table 1).

We have avoided considering any correction factors such as k_C, k_N , k_P or k_S so as to minimise any possible over- or underestimation of the variables presented in Table 2. Therefore, values of these variables are presented as the difference between fumigated and non-fumigated samples and represent only relative measures of microbial biomass. Apart from total microbial S none of the other microbial biomass measurement showed any significant effect of season or difference among soil types. There was a significant increase in the amounts of total S present in all soils during the summer. This lack of seasonal effect on microbial biomass can be attributed to the unusual mild seasonal variation, that is, frequent rainfall and relatively high temperature during the period of this study. Microbial activity measurements (basal respiration and substrate-induced respiration) showed significant increases in autumn, which was consistent for all soil types. Measurements of dehydrogenase enzyme activity (an enzyme secreted by living micro-organisms), showed significantly higher release of INTF in the summer than the autumn season. However, there was no significant seasonal effect on the FDA hydrolysis potential (hydrolysed by a battery of biotic and abiotic enzymes such as proteases, lypases and easterases) in any of the soil types.

Comparison between farm types (dairy vs. sheep–beef)

Farms type has been compared across all the soil types. Therefore, there are 12 replicates for each farm type. As expected, being a higher input system, soil nutrient status (P, SO_4, NO_3 and NH_4) in dairy farms was generally higher than that for sheep–beef farms (Table 3). The greatest significant difference was in level of Olsen P values which were about 60–70% higher under dairying. Soil pH in dairy farms was significantly higher than in sheep–beef farms. However, total C and N values were significantly higher in sheep–beef than in dairy farms. Similarly, the amounts of mineralisable N in all seasons were much higher in the sheep–beef. These favourable values for sheep–beef farms were particularly higher in Otorohanga silt loam soils which also contained significantly higher amounts of total C and N than other farms. This may be associated with the relative time index of conversion of native forest to grasslands.

Of the microbial biomass measurements, the sheep–beef farms generally had significantly higher values than dairy farms (Table 4). Microbial C, N, SO_4 and total S values were significantly higher for sheep–beef than dairying. Microbial carbon values measured in both farming types were about 20-30% higher than that found in yellow-brown pumice pastoral soils (Wardle & Ghani, 1995). The ratios of soil C:N to microbial C:N and microbial C:N showed no consistent pattern between these two types of farms. Microbial activity

Table 1 Seasonal fluctuations in soil physical, chemical and biochemical properties.

Variables	Sampling	Soils			SED
		Horotiu	Tirau	Otorohanga	
Physical					
Hydraulic Conductivity (mm/h)	Spring, 95	575.00	432.00	319.00	176.0
Soil moisture (%)	Spring, 95	77.70	83.70	95.80***	3.20
	Summer, 95	49.60	54.20	65.70**	4.26
	Autumn, 96	54.60	59.20	74.10***	4.69
Chemical & Biochemical					
pH	Spring, 95	5.80*	5.60	5.60	0.10
	Summer, 95	5.57	5.40	5.39	0.13
	Autumn, 96	5.68	5.49	5.46	0.12
Olsen P (µg/g soil)	Spring, 95	33.40	45.10	31.60	10.11
	Summer, 95	33.80	42.70	29.40	9.40
	Autumn, 96	41.00	54.50	41.80	10.08
SO_4 (µg/g soil)	Spring, 95	21.40*	25.40	29.60	4.30
	Summer, 95	41.10	37.60	46.10	14.00
	Autumn, 96	35.30**	61.40	75.90	22.10
Organic S (µg/g soil)	Spring, 95	11.30	9.70	11.10	1.50
	Summer, 95	11.00	9.90	11.80	2.43
	Autumn, 96	9.06	12.68	12.35	1.81
Extractable C (µg/g soil)	Spring, 95	161.10	186.40	255.80***	12.40
	Summer, 95	235.00	258.00	349.00***	26.60
	Autumn, 96	226.30	263.80	338.50***	23.40
Total soil C (%)	Spring, 95	9.08	9.71	12.09***	0.50
	Summer, 95	8.68	9.30	12.39***	0.56
	Autumn, 96	8.40	9.70	12.16***	0.51
Extractable N (µg/g soil)	Spring, 95	64.60	78.70	68.80	6.87
	Summer, 95	42.70	45.70	57.40*	4.62
	Autumn, 96	44.00	44.30	51.00	4.60
NO_3-N (µg/g soil)	Spring, 95	36.10	48.40	43.70	7.35
	Summer, 95	51.50	34.40	40.80	13.10
	Autumn, 96	34.10	32.10	35.70	8.43
NH_4-N (µg/g soil)	Spring, 95	3.14	1.66	2.24	0.57
	Summer, 95	2.10	2.50	2.70	0.57
	Autumn, 96	2.90	3.90	1.30	2.85
Mineralisable N (µg/g soil)	Spring, 95	195.70	215.10	237.80**	18.22
	Summer, 95	237.40	246.20	293.70**	22.80
	Autumn, 96	254.20	259.20	292.90*	20.82
Total soil N (%)	Spring, 95	0.91	0.91	1.09**	0.06
	Summer, 95	0.86	0.91	1.13**	0.72
	Autumn, 96	0.84	0.94	1.14***	0.06
Total soil C:N	Spring, 95	10.09	10.62	10.90	0.15
	Summer, 95	10.00	10.24	10.81	0.25
	Autumn, 96	9.99	10.55	10.85**	0.15

* significant at P= <0.1, ** significant at P = <0.05, *** significant at P = <0.01 levels of significance

measurements were not conclusive but tended to be higher on the sheep–beef than dairy farms. In the spring season, FDA hydrolysis, which is caused by a range of enzymes, showed significantly higher absorbance values for sheep–beef than dairy farms. However, this effect disappeared in subsequent summer and autumn samplings.

Conclusions

With the exception of basal respiration and total microbial S, seasonal variations in most of the microbial measurements appeared to be within 15% of the mean values. Variation between the three soil types was largely caused by the Otorohanga soils, which had greater total C

Table 2 Seasonal fluctuations in soil microbial biomass, microbial and enzyme activities.

Variables	Sampling	Soils			SED
		Horotiu	Tirau	Otorohanga	
Microbial biomass					
Microbial C (µg/g soil)	Spring, 95	518.00	604.00	609.00	30.80
	Summer, 95	587.00	573.00	605.00	43.20
	Autumn, 96	522.00	565.00	597.00	72.90
Microbial N (µg/g soil)	Spring, 95	123.00	181.00	187.00**	34.00
	Summer, 95	148.40	141.50	151.80	12.90
	Autumn, 96	150.90	156.80	153.40	11.30
Total soil C:Microbial C	Spring, 95	179.60	161.10	199.10***	12.80
	Summer, 95	148.70	162.90	205.70***	10.80
	Autumn, 96	161.00	184.00	217.00*	28.90
Soil N:Microbial N	Spring, 95	86.40**	60.00	64.40	14.20
	Summer, 95	59.60	64.50	75.90**	4.20
	Autumn, 96	56.10	61.00	73.40***	4.50
Microbial C:N	Spring, 95	4.60	3.05	3.55	0.50
	Summer, 95	4.04	4.07	4.10	0.21
	Autumn, 96	3.40	3.59	3.80	0.38
Microbial SO_4 (µg/g soil)	Spring, 95	4.70	2.10	3.20	0.72
	Summer, 95	2.15	3.44	4.03	0.87
	Autumn, 96	4.16	3.30	2.84	1.58
Microbial Total S (µg/g soil)	Spring, 95	9.70	9.80	10.00	0.73
	Summer, 95	17.00	11.50	10.30	3.77
	Autumn, 96	8.30	9.40	5.90	3.00
Microbial P (µg/g soil)	Spring, 95	236.00	180.00	197.00	41.00
Microbial activity					
Basal Respiration (CO_2-C/h)	Spring, 95	3.75	4.05	3.40	0.46
	Summer, 95	2.12**	3.06	3.15	0.20
	Autumn, 96	7.37	8.46	7.20	0.67
SIR (CO_2-C/h)	Spring, 95	23.90	32.20**	24.90	3.43
	Summer, 95	19.80	19.20	19.20	2.75
	Autumn, 96	37.70	38.20	35.60	3.39
BR:SIR	Spring, 95	0.16	0.13	0.14	0.02
	Summer, 95	0.12	0.16	0.17	0.02
	Autumn, 96	0.20	0.23	0.20	0.02
Enzyme activity					
Dehydrogenase	Spring, 95	3.12	4.57	2.92	0.68
(µg INTF/g soil/h)	Summer, 95	5.06	4.17	4.25	0.93
	Autumn, 96	3.3	2.88	2.46	0.85
FDA hydrolysis	Spring, 95	0.776	0.756	0.80**	0.02
(absorbance)	Summer, 95	0.786	0.806	0.79	0.02
	Autumn, 96	0.762	0.769	0.78	0.02

* significant at P= <0.1, ** significant at P = <0.05, *** significant at P = <0.01 levels of significance

and N. Nutrient values were generally higher in dairy than sheep–beef farms. Assuming all soils selected for this study were converted to pastoral farming approximately at the same time scale, then early findings from this study indicate that it is not necessarily true to associate high nutrient input soils with high microbial activity. This was the case with sheep–beef farms which had lower input, but generally higher amounts or higher activity of microbial biomass than dairy farms. Higher nutrient conservation in microbial biomass is considered to be a "good thing". We need further studies to examine whether these differences in soil microbial components between the farming types are consistent on a wider scale.

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Table 3 Effect of farm types on soil physical, chemical and biochemical properties.

Variables	Sampling	Dairy	Sheep–beef	SED
Physical				
Hydraulic Conductivity (mm/h)	Spring, 95	602.0	289.0	349.0
Soil moisture (%)	Spring, 95	83.80	87.80***	2.47
	Summer, 95	53.10	59.80*	3.48
	Autumn, 96	60.60	64.70	3.83
Chemical & Biochemical				
pH	Spring, 95	5.9**	5.6	0.12
	Summer, 95	5.6**	5.3	0.11
	Autumn, 96	5.7**	5.4	0.10
Olsen P (µg/g soil)	Spring, 95	46.80***	26.50	8.25
	Summer, 95	43.10**	27.50	7.70
	Autumn, 96	56.60**	34.90	8.23
SO_4 (µg/g soil)	Spring, 95	21.10	29.80	15.60
	Summer, 95	53.50**	29.70	11.41
	Autumn, 96	64.00	51.00	18.09
Organic S (µg/g soil)	Spring, 95	10.27	11.17	1.20
	Summer, 95	11.90	9.93	1.98
	Autumn, 96	12.01	10.72	1.48
Extractable C (µg/g soil)	Spring, 95	144.10	258.10***	10.10
	Summer, 95	246.00	315.00**	21.70
	Autumn, 96	255.90	296.50**	19.13
Total soil C (%)	Spring, 95	9.50	11.08***	0.41
	Summer, 95	9.37	10.88**	0.46
	Autumn, 96	9.28	10.89	0.42
Extractable N (µg/g soil)	Spring, 95	66.80	74.60**	5.61
	Summer, 95	46.60	50.60	3.77
	Autumn, 96	40.70	52.10***	3.79
NO_3-N (µg/g soil)	Spring, 95	50.40***	35.00	6.00
	Summer, 95	40.00	44.50	10.70
	Autumn, 96	35.00	32.90	6.88
NH_4-N (µg/g soil)	Spring, 95	2.42	2.45	0.47
	Summer, 95	2.16	2.81	0.47
	Autumn, 96	3.50	2.00	2.33
Mineralisable N (µg/g soil)	Spring, 95	163.90	268.50***	14.88
	Summer, 95	226.20	292.00***	18.62
	Autumn, 96	255.10	282.40*	14.00
Total soil N (%)	Spring, 95	0.92	1.03**	0.05
	Summer, 95	0.90	1.03**	0.06
	Autumn, 96	0.92	1.03**	0.05
Total soil C:N	Spring, 95	10.33	10.74**	0.12
	Summer, 95	10.27	10.43	0.20
	Autumn, 96	10.27	10.66**	0.12

* significant at P= <0.1, ** significant at P = <0.05, *** significant at P = <0.01 levels of significance

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Table 4 Effect of farm types on soil microbial biomass, microbial properties and enzyme activities.

Variables	Sampling	Dairy	Sheep–beef	SED
Microbial biomass				
Microbial C (µg/g soil)	Spring, 95	527.00	626.00***	25.10
	Summer, 95	569.00	608.00	35.20
	Autumn, 96	504.00	618.00**	59.50
Microbial N (µg/g soil)	Spring, 95	172.00	156.00	27.70
	Summer, 95	133.20	161.30**	10.56
	Autumn, 96	147.30	160.10***	9.21
Total soil C:Microbial C	Spring, 95	185.00	175.20	10.40
	Summer, 95	160.00	178.90**	8.90
	Autumn, 96	187.00	191.00	23.60
Soil N:Microbial N	Spring, 95	71.00	69.50	11.60
	Summer, 95	69.30	64.00	3.40
	Autumn, 96	60.29	60.47	3.70
Microbial C:N	Spring, 95	3.70	4.24**	0.41
	Summer, 95	4.39**	3.81	0.17
	Autumn, 96	3.45	3.81**	0.30
Microbial SO_4 (µg/g soil)	Spring, 95	2.11	3.49***	0.60
	Summer, 95	2.39	4.02**	0.71
	Autumn, 96	2.94	3.92	1.29
Microbial Total S (µg/g soil)	Spring, 95	7.33	11.92***	0.60
	Summer, 95	7.60	11.60**	3.08
	Autumn, 96	5.80	9.30	3.25
Microbial P (µg/g soil)	Spring, 95	196.00	213.00	33.50
Microbial activity				
Basal Respiration (CO_2-C/h)	Spring, 95	2.83	4.64***	0.37
	Summer, 95	3.04	2.51**	0.16
	Autumn, 96	7.45	7.91	0.55
SIR (CO_2-C/h)	Spring, 95	25.70	28.30	2.80
	Summer, 95	20.40	18.30	2.24
	Autumn, 96	36.90	37.40	2.77
BR:SIR	Spring, 95	0.11	0.17**	0.02
	Summer, 95	0.17	0.14**	0.20
	Autumn, 96	0.21	0.21	0.02
Enzyme activity				
Dehydrogenase	Spring, 95	n.d	3.22	
(µg INTF/g soil/h)	Summer, 95	4.12	4.87	0.75
	Autumn, 96	2.74	3.03	0.69
FDA hydrolysis	Spring, 95	0.744	0.813**	0.013
(absorbance)	Summer, 95	0.792	0.795	0.018
	Autumn, 96	0.775	0.763	0.018

* significant at P= <0.1, ** significant at P = <0.05, *** significant at P = <0.01 levels of significance

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