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SOIL CHANGES ASSOCIATED WITH CESSATION OF SHEEP GRAZING IN THE CANTERBURY HIGH COUNTRY, NEW ZEALAND

Summary: Soil characteristics were examined within and adjacent to two vegetation exclosures near Porters Pass, Canterbury retired from grazing 45 years ago. Soils were analysed for a range of simple physical (topsoil depth, bulk density), chemical (pH, exchangeable cations, P, S, total C and N) and biochemical (microbial carbon) properties to determine whether the vegetation recovery inside the exclosures was reflected in soil differences. At both sites there were few significant differences between the exclosure and the surrounding grazed area, despite vegetation recovery since exclusion of grazing. At Starvation Gully topsoil depth and Na were higher, and bulk density, pH, K, total C, total N and microbial C mass, and the microbial C to total C ratio were lower in the exclosure. At Cloudy Knoll Ca, Mg, total C and N were higher and Na was lower in the exclosure. There was a marked contrast in the trends at the two sites, with slightly lower nutrient status and organic matter in the exclosure at Starvation Gully, and the reverse at Cloudy Knoll. The differences between the sites probably reflect differences in the partitioning of nutrients and organic matter between vegetation, litter and soil at the two sites. The results suggest a slow rate of change of soil properties following cessation of grazing and the need to sample soils, litter and vegetation when determining trends in organic matter and chemical fertility.

Keywords: indicators; high country; sustainability; microbial carbon; nutrients.

Introduction

Soil degradation has been implicated as a cause of the poor vegetation condition over much of the unimproved tussock grassland in the South Island high country and as a threat to the sustainability of extensive pastoralism (Parliamentary Commissioner for the Environment, 1991; South Island High Country Review Working Party, 1994). A key requirement for assessment of sustainability is an ability to monitor indicators of temporal trends in natural resources such as soils and vegetation, and to understand the impact of land use on these trends (Basher, Floate and Watt, 1992). Vegetation degradation (e.g., loss of biomass and species diversity) in the presence of grazing by stock, and subsequent recovery in the absence or reduction of grazing has been documented at many sites in the Canterbury high country (e.g., Scott, Dick and Hunter, 1988; Rose, Platt and Frampton, 1995; Treskonova, 1991). The extent of soil changes associated with this degradation is less clear. However, loss of organic matter and decline in soil nutrient status has been implicated as a cause of *Hieracium* spread in the high country (Parliamentary Commissioner for the Environment, 1991).

Inferences about soil trends have been made from an understanding of the processes associated with grazing and burning of unimproved tussock grassland (O'Connor, 1987; Basher, Meurk and Tate, 1990; McKendry and O'Connor, 1990; O'Connor and Harris, 1992). However little scientific data are available to assess the extent of soil degradation and its relationship with land use (McIntosh, Allen and Patterson, 1994a; McIntosh *et al*., 1994b). Temporal soil changes in unimproved grasslands have been examined in seasonally dry and humid high country. In the humid high country of the east Otago uplands, there was little change in pH, organic C, and total N between 1978 and 1994 (McIntosh *et al*., 1994b).

Currently research on soil degradation in the high country is focusing on changes in organic matter and nutrient status, in an attempt to identify sensitive "indicators" (parameters that indicate the condition of the environment) that may be used to assess trends in these properties. A living fraction of organic matter, the microbial biomass, has been suggested (Powlson, Brookes and Powlson, 1987) as a more sensitive measure of change in soil organic matter status than the total amount of organic matter. Microbial biomass can provide an early indication of change in total soil organic matter because: (i) it has a rapid turnover (1 -

2 years); and (ii) is sensitive to variation in food supply, associated with changes in vegetation or environmental stress. The ratio of microbial biomass carbon to total soil organic carbon has been shown to be a sensitive indicator of changes in soil organic matter for a variety of land uses (Sparling, 1992).

Comparative studies, where differential management treatments have been applied, are one approach to gathering monitoring data and testing indicators of degradation (McIntosh *et al*., 1989). Vegetation exclosures have been established at several sites in the South Island high country and provide opportunities for examining soil changes associated with cessation of sheep grazing.

This study compared soil characteristics within and adjacent to vegetation exclosures at two sites near Porters Pass (called Starvation Gully and Cloudy Knoll), to investigate whether vegetation recovery was reflected in soil differences. The exclosures were retired from grazing in 1948 and there are now vegetation differences between the ungrazed exclosures and the surrounding grazed land. The objectives of the study were to:

1) characterise soil conditions within and adjacent to the exclosures;
2) determine whether soil differences were associated with vegetation differences resulting from exclusion of grazing;
3) test the effectiveness of a range of potential soil degradation indicators that might be used in a soil monitoring programme in Canterbury.

Several simple indicators of organic matter status and soil fertility were tested. It was assumed that degradation would be an ongoing process in the grazed area, but would have been halted in the exclosures leading to differences between the grazed and ungrazed areas. The study also provides information on short-range soil variability that is essential in designing appropriate sampling strategies for monitoring programmes. Results from the individual sites are described in Basher and Hewitt (1993) and Lynn and Basher (1994). One of the sites (Starvation Gully) was previously examined by Gregg (1964) after 15 years of grazing exclusion. Because of differences in sampling methodology the numerical results are not directly comparable; however the trends observed in 1964 can be compared with those observed 30 years later.

Study sites

The exclosures are one chain square (20 x 20 m) plots protected from grazing by stock and hares since 1948 at Starvation Gully (NZMS 260 K35/ 062674) and Cloudy Knoll (NZMS 260 K34/

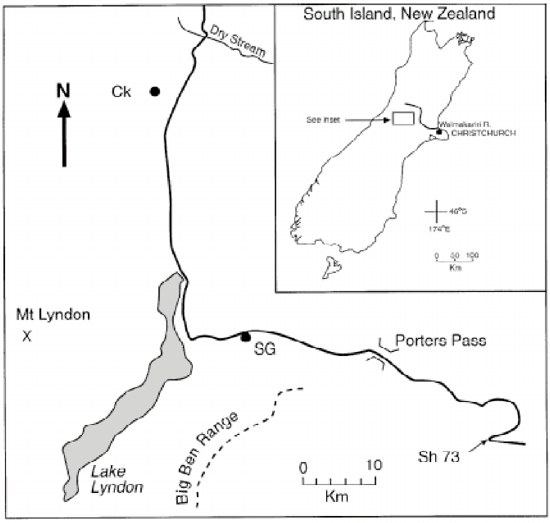

Figure 1: *Location of study sites. SG - Starvation Gully, CK - Cloudy Knoll.*

049705) located on the western side of Porters Pass (Fig. 1). Site characteristics and soils are similar at both sites (Table 1). Soil pits excavated within and outside both exclosures showed that morphologically the soils are very similar with Ah/ Bw/C profile form. However, there is high variability in depth of horizons especially the A horizon (see Results). The chemical properties of the soils are also similar, although phosphorus levels at Cloudy Knoll are considerably higher and carbon tends to be slightly lower (Tables 3-6).

Vegetation changes have been monitored since 1948 (Canterbury Regional Council, unpublished data) along two 20 m transects within the exclosures, and along a single transect outside the exclosures. Neither the control sites or the grazed areas have been oversown, fertilised or burnt to our knowledge. At Starvation Gully there is now a marked vegetation contrast between the exclosure and the surrounding land (Fig. 2), whereas at Cloudy Knoll there is only a subtle vegetation contrast between the exclosure and the surrounding land (Fig. 3).

Table 1: *Site characteristics (soil set from New Zealand Soil Bureau, 1968; soil class after Hewitt, 1992).*

	Starvation Gully	Cloudy Knoll
Elevation	870 m	810 m
Aspect	north north west	east south east
Slope	25°	29°
Rainfall	*c*.1000 mm yr^{-1}	*c*.1000 mm yr^{-1}
Soil set	Tekoa	Tekoa
Soil class	Typic Orthic Brown	Typic Orthic Brown

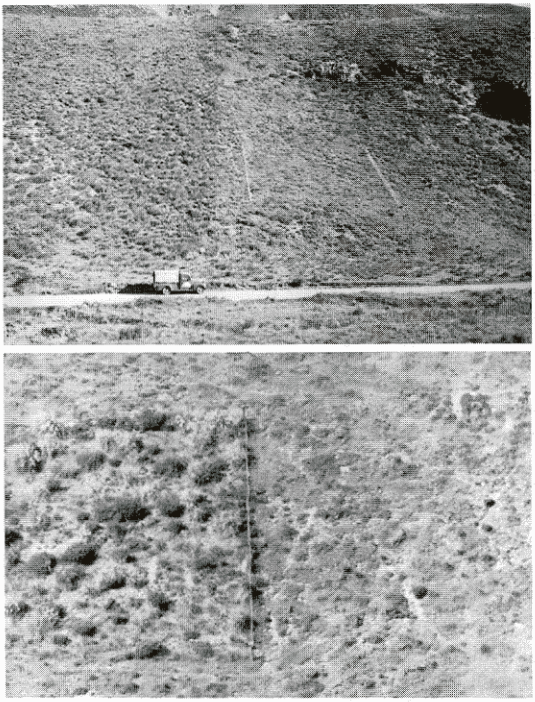

Figure 2: *The Starvation Gully exclosure in (a) 1949 and (b) 1995. Soils sampled from the grazed area were to the right of the exclosure. Note the dense tall tussock grassland to the left of the exclosure and boundary fence in 1949. The boundary fence was removed in the mid 1970s.*

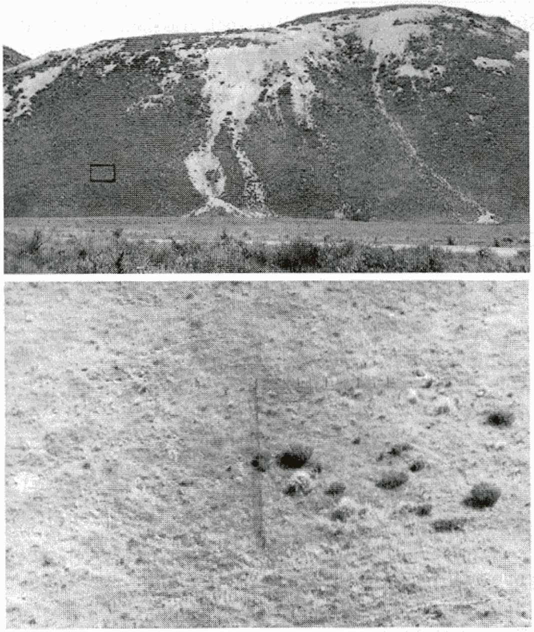

Figure 3: *The Cloudy Knoll exclosure in (a) 1948 and (b) 1995. Soils sampled from the grazed area were to the left of the exclosure.*

In 1948, vegetation at Starvation Gully was characterised by short tussock grassland dominated by *Festuca novae-zelandiae*[1], *Poa colensoi*, *Agrostis capillaris*, and *Anthoxanthum odoratum* with about 17% bare ground (Canterbury Regional Council, *unpubl. data*). Present vegetation is described in Table 2. Bare ground in the exclosure reduced to about 5% within 5 years of exclusion of grazing, and is similar today. Outside the exclosure bare ground remains about 15%. Tussock and shrub litter is abundant inside the exclosure, while outside there is little litter on the surface. Outside the exclosure vegetation is generally much shorter statured and open. The substantial differences in species composition, plant biomass, and the extent of litter and bare ground indicate considerable recovery of vegetation inside the exclosure. *Hieracium pilosella* has been present in the area at least since the 1960s. Gregg (1964) records *H. pilosella* as a significant component of the vegetation both within and outside the exclosure.

In 1949 vegetation at Cloudy Knoll was characterised by short tussock grassland with abundant *Festuca novae-zelandiae*, *Poa colensoi*, *Anthoxanthum odoratum*, and about 18% bare ground (Canterbury Regional Council, *unpubl. data*). Present vegetation is described in Table 2. Bare ground within the exclosure reduced to about 8% within 5 years of exclusion of grazing and is similar today. Both inside and outside the exclosure a vegetated, stepped, erosional microtopography is evident with a small bare ground component of rock fragments and exposed topsoil. Bare ground outside the exclosure appears slightly greater than inside the exclosure. The erosional microtopography results in considerable variation in topsoil depth both inside and outside the exclosure (see Results). Vegetation recovery inside the exclosure is not marked compared to Starvation Gully. Snow tussock and shrubs are more common inside the exclosure, along with less *Hieracium pilosella* and bare ground. There is little litter either within or outside the exclosure.

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[1] Botanical nomenclature follows Cheeseman (1925), Allan (1982), Webb, Sykes and Garnock-Jones (1988), and Connor and Edgar (1987).

Table 2: *Vegetation at the study sites.*

	Inside exclosure	Outside exclosure
Starvation Gully	Tall tussock grassland-shrubland. Dominated by *Chionochloa flavescens*; common: *Festuca novae-zelandiae*, *Poa colensoi*, *Aciphylla aurea*, *Dracophyllum acerosum*; rare: *Hieracium* (*H. praealtum* and *H. lepidulum*). Tall tussocks and *Dracophyllum* up to c.1 m tall.	Low statured adventive grassland. Common: *Agrostis capillaris*, *Anthoxanthum odoratum*, and *Hieracium* (mainly *H. pilosella*, with *H. lepidulum*); scattered *Festuca novae-zelandiae* and *Poa colensoi*. Maximum height *c*.30 cm
Cloudy Knoll	Low statured (20-30 cm high) adventive grassland. Dominated by *Agrostis capillaris* and *Anthoxanthum odoratum*, with some *Hieracium* (*H. pilosella* and *H. praealtum*), and *Aciphylla* spp.; scattered *Festuca novae-zelandiae* and <1 to 2 m tall *Dracophyllum acerosum*; a few 0.5->1m tall narrow leaved snow tussocks (*Chionochloa macra*), *Celmisia* spp. and *Discaria toumatou* are present.	Low statured (20-30 cm high) adventive grassland. Dominated by *Agrostis capillaris* and *Anthoxanthum odoratum with* scattered *Festuca novae-zelandiae*; some *Hieracium* (*H. pilosella*, and *H. praealtum*) and scattered low shrubs (*Discaria toumatou*, *Cassinia* spp. and *Leucopogon fraseri*).

Both study sites are part of large grazing blocks. The Starvation Gully site is located in a 2800 ha block which has been grazed each year by between 700 and 4000 sheep for up to eight weeks in late autumn, and set stocked by 800 wethers. Currently 2500 to 3000 ewes and wethers graze the block for nine weeks in late autumn (R. James, runholder, *pers. comm.* 1995). The Cloudy Knoll site was originally part of a 2400 ha block set stocked by 1300 wethers. The block was reduced to about 280 ha with a retirement fence constructed in 1973. Currently 1000 ewes graze this block for four to six weeks during late February to mid April. In some seasons the block is grazed by 50 to 60 heifers for six to eight weeks during late summer to early autumn (M. Milliken, runholder, *pers. comm.* 1995).

Methods

Soils were described and sampled within the exclosure and within an adjacent similar sized area outside the exclosure. Each of these 20 x 20 m areas was divided into quarters, giving four "replicates" for sampling. Within each quarter 10 soil cores were randomly collected and bulked to give a single sample from each quarter for chemical analysis. All types of inter-tussock soil surface conditions (bare, litter covered, vegetation covered) were sampled if randomly encountered, except that dung-covered areas in the grazed area were avoided. Samples were collected at two depth increments (0-5, 5-15 cm). Ten individual samples of both depth increments were collected inside and outside the exclosure using a stainless steel cylinder (6.1 cm internal diameter) for bulk density determination. The mean values of bulk density in each quarter were used to calculate mass of carbon and nitrogen. Topsoil depth was measured at each of the 10 sites within each quarter where soil cores were collected.

Soil samples were analysed for pH, organic carbon (C_{tot}), total nitrogen (N), exchangeable cations (Ca, Mg, K, Na), Olsen-phosphorus (P), and phosphate-extractable sulphate (S) using the methods of Blakemore, Searle and Daly (1987). Microbial biomass carbon (C_{mic}) was measured using two different methods to determine if the analysis method affected results. At Starvation Gully both the substrate-induced respiration method (SIR) of West and Sparling (1986) and the fumigation extraction method (FE) of Tate, Ross and Feltham (1988) were used. The rate of respiration in the SIR method was converted to microbial biomass using the revised calibration of Sparling *et al.* (1990). At Cloudy Knoll only the fumigation extraction method was used.

Differences between mean values of soil analyses within and outside the exclosure were compared using the *t*-test.

Results

Starvation Gully

Topsoil depth (Table 3) was 3 cm lower outside the exclosure than inside, and was more variable. Inside

Table 3: *Results of soil physical and chemical analyses, Starvation Gully.* [1] *standard error of the mean;* [2] *coefficient of variation;* [3] *t-test for differences between mean values inside and outside the exclosure, * = significant at* $P<0.05$*, ** = significant at* $P<0.01$*, NS = not significant ;* [4] *milliequivalents per 100 g of soil.*

		Inside exclosure			Outside exclosure			Significance
		Mean±S.E. [1]	Range	C.V.[2] (%)	Mean±S.E.	Range	CV (%)	level[3]
Topsoil depth	(cm)	17.5±0.8	8-30	28	14.4±1.0	4-32	42	**
Bulk density	0-5 cm	1.0±0.03	0.9-1.0	5	1.1±0.03	1.01-1.20	5	*
($g\ cm^{-3}$)	5-15 cm	1.1±0.03	1.1-1.2	4	1.1±0.05	1.0-1.2	10	NS
pH	0-5 cm	5.5±0.05	5.4-5.6	2	5.8±0.03	5.7-5.8	1	**
	5-15 cm	5.4±0.06	5.3-5.6	2	5.5±0.05	5.4-5.6	2	NS
Olsen P	0-5 cm	4.8±0.3	4-5	11	4.8±0.3	4-5	11	NS
($mg\ kg^{-1}$)	5-15 cm	3.8±0.5	3-5	26	3.8±0.5	3-5	26	NS
SO_4-S	0-5 cm	1.5±0.3	1-2	38	2.3±0.3	2-3	22	NS
($mg\ kg^{-1}$)	5-15 cm	1.8±0.9	0-4	98	2.0±0	2	0	NS
Ca (me%[4])	0-5 cm	5.89±0.76	4.04-7.75	26	6.07±0.47	4.77-6.85	16	NS
	5-15 cm	3.19±0.48	2.39-4.57	30	2.67±0.18	2.29-3.08	14	NS
Mg (me%)	0-5 cm	1.44±0.13	1.15-1.75	18	1.41±0.09	1.17-1.56	13	NS
	5-15 cm	0.91±0.10	0.74-1.19	23	0.75±0.04	0.67-0.86	12	NS
K (me%)	0-5 cm	0.72±0.02	0.65-0.76	7	0.91±0.05	0.8-1.02	10	**
	5-15 cm	0.52±0.03	0.46-0.60	12	0.59±0.05	0.47-0.69	16	NS
Na (me%)	0-5 cm	0.09±0.01	0.08-0.10	11	0.06±0.003	0.06-0.07	8	*
	5-15 cm	0.11±0.03	0.07-0.19	49	0.08±0.003	0.07-0.08	8	NS

the exclosure topsoil depth ranged from 8 to 30 cm and outside from 4 to 32 cm. Bulk density at 0-5 cm depth was lower inside the exclosure. Outside the exclosure bulk density was greater at 0-5 cm depth than at 5-15 cm, whereas inside the exclosure bulk density showed the normal trend of an increase with depth. This may well be an animal trampling effect on the soil surface in the grazed area.

The soil fertility analyses show the soils were very low (ratings from Blakemore, Searle and Daly, 1987) in P, S and Na, but have medium levels of Ca, Mg, and K (Table 3). There were no significant differences in P, S, Ca and Mg between the exclosure and the grazed area for either depth increment. At 0-5 cm depth, pH and K were lower inside the exclosure while Na was higher.

The organic matter analyses (Table 4) indicated no statistically significant differences in concentrations of total C and N, although both were higher outside the exclosure at 0-5 cm depth. The total mass of C and N in the top 5 cm were higher outside the exclosure, a result of higher concentrations of C and N and higher bulk density. The concentration of microbial C was higher outside the exclosure although this was significant only for 0–5 cm depth using the fumigation-extraction method. Microbial C concentrations were more variable outside the exclosure, with individual values varying by a factor of two, and this variation limits the statistical significance of the result. The mass of microbial C was significantly higher outside the exclosure when calculated over the total sampling depth of 15 cm for the substrate-induced respiration method, and was significantly higher for 0-5 cm depth using the fumigation extraction method. The ratio of microbial to total C tended to be higher at both depth increments outside the exclosure. This difference was not significantly different for the substrate-induced respiration method but was significant for 0-5 cm and 0-15 cm for the fumigation extraction method. Values of microbial C determined by the fumigation extraction method were all higher than those determined by the substrate-induced respiration method. In most cases microbial C by fumigation extraction was 1.2 to 1.3 times higher than microbial C by substrate-induced respiration, although for a few samples differences were either greater or smaller. The trends shown by both sets of analyses were broadly similar although there were more significant differences between inside and outside the exclosure with the fumigation extraction method.

Table 4: *Results of organic matter analyses, Starvation Gully. SIR - measured by substrate-induced respiration method. FE - measured by fumigation extraction method;* C_{mic}/C_{tot} *- ratio of microbial carbon mass to total carbon mass.*

		Inside exclosure			Outside exclosure			Significance
		Mean±S.E.	Range	C.V. (%)	Mean±S.E.	Range	CV (%)	level
C (%)	0-5 cm	6.70±0.3	5.9-7.2	9	7.3±0.4	6.2-8.0	11	NS
	5-15 cm	4.83±0.3	4.1-5.6	13	4.7±0.3	4.2-5.2	11	NS
C mass	0-5 cm	3.26±0.16	2.80-3.50	10	4.14±0.16	3.70-4.41	8	*
($kg\ m^{-2}$)	5-15 cm	5.53±0.47	4.55-6.81	17	5.06±0.13	4.75-5.37	5	NS
	0-15 cm	8.79±0.61	7.35-10.32	14	9.20±0.25	8.46-9.48	5	NS
Microbial C	0-5 cm	954±33	858-1007	7	1107±168	637-1435	30	NS
($mg\ kg^{-1}$) SIR	5-15 cm	614±40	530-692	13	671±12	647-700	3	NS
Microbial C	0-5 cm	0.046±0.002	0.041-0.050	9	0.062±0.009	0.037-0.077	28	NS
mass ($kg\ m^{-2}$)	5-15 cm	0.070±0.006	0.059-0.084	16	0.073±0.004	0.064-0.083	11	NS
SIR	0-15 cm	0.117±0.008	0.033-0.010	13	0.135±0.006	0.120-0.150	9	*
$C_{mic}/C_{tot}*10^{-2}$	0-5 cm	1.43±0.01	1.40-1.45	2	1.53±0.24	0.86-1.89	31	NS
SIR	5-15 cm	1.27±0.04	1.20-1.37	6	1.44±0.07	1.29-1.61	10	NS
	0-15 cm	1.33±0.03	1.28-1.39	4	1.48±0.09	1.27-1.66	12	NS
Microbial C	0-5 cm	1219±50	1090-1317	8	1650±125	1404-1957	15	*
($mg\ kg^{-1}$) FE	5-15 cm	798±16	768-830	4	840±37	761-917	9	NS
Microbial C	0-5 cm	0.059±0.002	0.054-0.064	7	0.094±0.007	0.082-0.114	16	*
mass ($kg\ m^{-2}$)	5-15 cm	0.091±0.003	0.086-0.101	8	0.091±0.007	0.078-0.109	15	NS
FE	0-15	0.150±0.005	0.142-0.165	7	0.185±0.014	0.159-0.223	15	NS
$C_{mic}/C_{tot}*10^{-2}$	0-5 cm	1.83±0.12	1.62-2.16	13	2.27±0.16	1.87-2.64	14	**
FE	5-15 cm	1.67±0.11	1.48-2.0	14	1.80±0.11	1.56-2.11	13	NS
	0-15 cm	1.73±0.11	1.59-2.06	13	2.01±0.13	1.70-2.35	13	*
N %	0-5 cm	0.33±0.01	0.30-0.37	9	0.38±0.02	0.32-0.43	12	NS
	5-15 cm	0.25±0.01	0.23-0.27	7	0.25±0.02	0.21-0.29	14	NS
N mass	0-5 cm	0.16±0.01	0.14-0.18	10	0.21±0.01	0.19-0.24	10	*
($kg\ m^{-2}$)	5-15 cm	0.28±0.02	0.26-0.33	11	0.27±0.01	0.25-0.28	5	NS
	0-15 cm	0.44±0.02	0.41-0.51	10	0.48±0.02	0.45-0.52	7	NS

Cloudy Knoll

There was no significant difference in mean topsoil depth (Table 5), although depths tended to be more variable inside the exclosure. Bulk densities were very similar inside and outside the exclosure for both 0-5 cm and 5-15 cm depths, and showed the normal trend of an increase with depth. Bulk density tended to be higher outside the exclosure but the mean value was influenced by one very low value outside the exclosure.

The soils were very low in S and Na, low in P, and have medium levels of Ca, Mg, and K (Table 5). There were no significant differences between the exclosure and the grazed area for either depth increment in pH, P, S and K. At 0-5 cm depth Ca, Mg and Na were lower outside the exclosure, as was Ca at 5-15 cm depth.

All the organic matter analyses showed lower values outside the exclosure although only some of the differences were significant (Table 6): total C concentration at 0-5 cm, total C mass at 5-15 cm, total N concentration at 0-5 and 5-15 cm, total N mass at 0-15 cm. There were no significant differences in microbial C, or microbial C/total C ratios although values were higher inside the exclosure.

Most of the significant differences were found at 0-5 cm depth (Ca, Mg, Na, C%, N%) with Ca, C mass and N% at 5-15 cm depth, and N mass over the total 0-15 cm sampling depth. Overall there are few significant differences associated with cessation of grazing. However the trends indicate slightly greater organic matter accumulation and nutrient status inside the exclosure.

Table 5: *Results of physical and chemical analyses, Cloudy Knoll.*

		Inside exclosure			Outside exclosure			Significance
		Mean±S.E.	Range	C.V. (%)	Mean±S.E.	Range	CV (%)	level
Topsoil depth	(cm)	16.4±0.9	6-33	33	17.0±0.7	10-25	24	NS
Bulk density	0-5 cm	1.0±0.04	0.9-1.1	8	1.1±0.10	0.8-1.2	18	NS
(t m^{-3})	5-15 cm	1.2±0.02	1.1-1.2	3	1.2±0.06	1.1-1.3	10	NS
pH	0-5 cm	5.65±0.03	5.6-5.7	1	5.68±0.03	5.6-5.7	1	NS
	5-15 cm	5.55±0.03	5.5-5.6	1	5.60±0.04	5.5-5.7	1	NS
Olsen P	0-5 cm	15.5±1.2	12-17	15	15.5±1.2	13-18	15	NS
(mg kg^{-1})	5-15 cm	11.8±0.9	10-14	15	12.0±0.9	10-14	15	NS
SO_4-S	0-5 cm	2.0±0	-	0	2.0±0	-	0	NS
(mg kg^{-1})	5-15 cm	2.5±0.3	2-3	23	2.5±0.3	2-3	23	NS
Ca (me%)	0-5 cm	6.09±0.26	5.43-6.67	9	4.91±0.16	4.43-5.08	6	*
	5-15 cm	3.63±0.12	3.41-3.96	7	3.25±0.15	2.91-3.64	9	**
Mg (me%)	0-5 cm	1.53±0.04	1.46-1.64	5	1.35±0.06	1.19-1.46	11	*
	5-15 cm	0.87±0.03	0.83-0.94	6	0.85±0.05	0.74-0.95	3	NS
K (me%)	0-5 cm	0.72±0.03	0.65-0.79	8	0.73±0.01	0.71-0.75	3	NS
	5-15 cm	0.45±0.01	0.43-0.49	6	0.49±0.02	0.45-0.52	7	NS
Na (me%)	0-5 cm	0.07±0.01	0.04-0.09	31	0.10±0.01	0.07-0.11	19	*
	5-15 cm	0.08±0.01	0.05-0.10	27	0.11±0.01	0.08-0.15	28	NS

Table 6: *Results of organic matter analyses, Cloudy Knoll.*

		Inside exclosure			Outside exclosure			Significance
		Mean±S.E.	Range	C.V. (%)	Mean±S.E.	Range	CV (%)	level
C (%)	0-5 cm	5.8±0.2	5.3-6.0	6	4.9±0.2	4.6-5.3	6	*
	5-15 cm	4.2±0.2	3.8-4.9	12	3.6±0.1	3.4-3.8	5	NS
C mass	0-5 cm	2.89±0.19	2.44-3.22	13	2.57±0.25	1.86-2.98	19	NS
(kg m^{-2})	5-15 cm	4.86±0.25	4.41-5.55	10	4.13±0.20	3.79-4.68	10	*
	0-15 cm	7.75±0.40	6.85-8.77	21	6.70±0.38	5.65-7.34	11	NS
Microbial C	0-5 cm	952±100	722-1209	18	766±18	714-797	5	NS
(mg kg^{-1}) FE	5-15 cm	571±52	474-714	21	448±18	412-501	8	NS
Microbial C	0-5 cm	0.048±0.007	0.034-0.064	27	0.041±0.003	0.031-0.046	17	NS
mass (kg m^{-2})	5-15 cm	0.066±0.005	0.057-0.081	16	0.052±0.005	0.045-0.066	19	NS
FE	0-15 cm	0.113±0.011	0.090-0.145	21	0.093±0.007	0.079-0.113	15	NS
$C_{mic}/C_{tot}*10^{-2}$	0-5 cm	1.65±0.16	1.25-2.02	19	1.57±0.06	1.47-1.73	7	NS
FE	5-15 cm	1.37±0.13	1.19-1.74	19	1.25±0.06	1.15-1.43	10	NS
	0-15 cm	1.47±0.1	1.21-1.85	19	1.39±0.1	1.28-1.54	8	NS
N %	0-5 cm	0.33±0.01	0.31-0.37	8	0.28±0.01	0.26-0.30	7	*
	5-15 cm	0.26±0.01	0.25-0.27	4	0.23±0.01	0.21-0.25	8	*
N mass	0-5 cm	0.17±0.01	0.14-0.20	15	0.15±0.01	0.12-0.16	14	NS
(kg m^{-2})	5-15 cm	0.30±0.01	0.28-0.31	4	0.27±0.01	0.23-0.29	10	NS
	0-15 cm	0.46±0.01	0.44-0.50	6	0.42±0.02	0.39-0.45	8	*

Soil variability

At both sites there was generally good agreement between "replicates". For most analyses coefficients of variation (C.V.) were less than 15%. The least variable property at both sites was pH with a C.V. of less than 2%. S and Na were more variable than other properties although the range of values recorded was very low for both. For most of the analyses that had a high C.V. the range of soil test values was low and the high C.V. simply reflected the low values of the soil test results. For example, S at 0-5 cm depth inside the exclosure at Starvation Gully had a C.V. of 38% but the sample values only ranged from 1-2 mg kg^{-1}. Individual values of topsoil depth were extremely variable (C.V. of 20-40%) but mean topsoil depth of each of the replicates showed better agreement (C.V. less than 10%).

Discussion

While the comparisons of grazing exclusion at the two sites have given slightly different results, the major feature is the slow rate of change of soil properties, despite a major change in vegetation at one of the sites. This is similar to the results obtained by McIntosh *et al*. (1994b) in the humid east Otago uplands and contrasts with results from seasonally dry high country (McIntosh *et al.,* 1994a).

At both sites examined in the present study there were few significant differences between the exclosure and the surrounding grazed area. There was a marked contrast in the trends when comparing the two studies. At Starvation Gully a number of the soil analyses showed the opposite trend to that expected, i.e., rather than a decrease in organic matter and fertility in the grazed area, the soils tend to have slightly higher nutrient status and organic matter. By comparison, the trends at Cloudy Knoll tended to suggest slightly lower soil nutrient and organic matter status under grazing.

At Starvation Gully the thinner topsoils, and higher bulk density at 0-5 cm depth are consistent with impacts of grazing and less dense vegetation cover outside the exclosure. Animal trampling is likely to have caused the higher bulk density, while relatively sparse vegetation and more bare ground provide the opportunity for wind and sheet erosion to reduce topsoil depth. Direct measures of erosion could be used to determine a cause and effect relationship between the shallower topsoils and erosion. Alternatively, the differences in topsoil depth may reflect recovery of topsoil depth inside the exclosure. However, mean topsoil depths determined in this study are less than those recorded by Gregg (1964) both inside and outside the exclosure. The magnitude of the difference between depths in 1964 and 1993 is greater outside the exclosure. Comparison of the two studies would suggest a thinning of topsoil of 2 to 3 cm in 30 years. This is at least an order of magnitude greater than could be accounted for by rates of surface erosion measured nearby on similar terrain and vegetation communities by Hayward (1969), perhaps suggesting that the differences result from differences in sampling. With the high C.V. for topsoil depth (24-42%), large sample numbers would be required to accurately determine mean topsoil depth (e.g., with a C.V. of 30%, to estimate the mean with standard error less than 5% would require 36 samples).

Lower pH inside the exclosure at Starvation Gully is the opposite trend to what might be expected as a result of cessation of grazing. A decrease in pH can occur under grazing largely as a result of nitrate leaching and nutrient loss or transfers. The more acid topsoil in the ungrazed exclosure suggests a vegetation impact rather than a grazing impact. The tall tussock-shrubland community may be producing a more acid litter, thus reducing pH in the soil. Certainly *Dracophyllum* is well known to have an acid litter and this may be affecting the whole plot. While the difference is statistically significant, the magnitude of the difference is relatively small (0.3 pH units). Given the amount of *Dracophyllum* in the exclosure it is perhaps surprising that the pH is not lower. The pHs recorded by Gregg (1964) are within 0.1 of a pH unit of those recorded in this study suggesting little change despite the significant growth of *Dracophyllum* within the last 30 years. At Cloudy Knoll, where there is little difference in vegetation inside and outside the exclosure plot, no difference in pH is evident.

The analyses of soil nutrient status showed few significant differences between the soils in the exclosures and those in the surrounding grazed areas. Differences in the major plant nutrients Ca and Mg at Cloudy Knoll were the only indications of lower soil nutrient status related to grazing. The higher level of K outside the exclosure at Starvation Gully may be a result of grazing, with greater K being cycled through urine outside the exclosure. The site had been recently grazed at the time of sampling. A more likely explanation, however is that it results from the substantial vegetation differences. Outside the exclosure rather more of the K is likely to be adsorbed in the soil because of the low biomass available to assimilate K, whereas inside the exclosure more K is likely to be contained within the biomass rather than the soil. Because the levels of P and S are so low in these unfertilised soils it is not surprising that there is no difference between the exclosure and the surrounding grazed area.

The indices of organic matter also showed no consistent differences across both sites. The slightly lower organic C and total N concentrations and mass inside the plot at Starvation Gully are surprising in view of the substantial recovery in vegetation condition after 45 years, and the greater plant biomass and litter. This may reflect partitioning of C and N between the soil and plant pools, with more of the total organic matter contained in the plant and litter pools inside the exclosure and more in the soil pool outside the exclosure. Although litter was not sampled in this study, the differences in total C and N mass, and microbial C mass between the exclosure and the grazed area could probably be accounted for by the litter alone at Starvation Gully. The higher microbial carbon biomass and microbial C/total C ratios outside the exclosure are also opposite to the trends anticipated with vegetation recovery. The microbial C estimates at Starvation Gully were obtained by two methods and clearly demonstrated that the observed trends are real and do not result from the analysis technique. At Cloudy Knoll the indices of organic matter status showed consistent trends for higher values inside the exclosure, although many of the differences were not significant. This applied to total C and N, and microbial C. The concentration and the mass of microbial C are higher inside the exclosure, but the difference is not significant for either of the sampling increments or the total sampling depth. Similarly the ratio of microbial C to total C is higher inside the exclosure but again the difference is not significant.

The results showed that the mass of organic matter at Starvation Gully was higher outside the exclosure (0-15 cm) than inside. However, if the results are recalculated on a horizon basis (assuming the bulk density at 5-15 cm is representative of the A horizon below 5 cm) then the total amount of organic matter in the A horizon is higher inside the exclosure because of the significantly greater A horizon depth. The differences in the mass of C, N or microbial C on a horizon basis are not statistically significant.

These results can be directly compared with Gregg (1964) who also found that organic matter was higher inside the exclosure, although not significantly so, suggesting that there has been little change in the last 30 years. Gregg (1964) compared the exclosure and surrounding grazed area with an adjacent area across a boundary fence that was in dense *Chionochloa flavescens* grassland (see Fig. 2), regarded as a remnant of pre-European vegetation. There were no significant differences between the exclosure and surrounding area in total carbon, nitrogen, inorganic phosphorus, and pH in the A horizon of the soils, although the grazed area tended to have lower levels of all nutrients and organic matter. However both areas had lower nitrogen, carbon and phosphorus than the area in dense tall tussock grassland.

It seems most likely that the observed differences between the sites reflect the partitioning of nutrients and organic matter between vegetation, litter and soil. There are marked contrasts in vegetation recovery at the two sites. At Starvation Gully, vegetation has recovered significantly with cessation of grazing to a tall tussock-shrubland community inside the exclosure with an adventive grass-short tussock-herb community outside the exclosure. There are major contrasts in species composition, plant biomass and litter resulting from cessation of grazing. By comparison, vegetation at the Cloudy Knoll exclosure shows little recovery after 46 years without grazing, with minor reestablishment of snow tussock and shrubs. The lack of a marked vegetation contrast at the Cloudy Knoll exclosure is probably related to the lack of significant local seed sources for re-establishment of snow tussocks and shrubs. Photos taken in 1948 and 1949 at both sites (Figs. 2 and 3) show that there are no snow tussocks near the Cloudy Knoll exclosure, whereas to the eastern side of the Starvation Gully exclosure there is a dense snow tussock grassland. At Starvation Gully changes induced by grazing are expressed in the vegetation whereas at Cloudy Knoll, where the vegetation differences are slight, changes are expressed in the soil. Gregg's (1964) results show that the percentage (by mass) of nutrients, C and N contained within the vegetation was higher in the dense tall tussock grassland than in the depleted grasslands. This suggests that with vegetation recovery there may be a reallocation of nutrients and organic matter from soil to vegetation and litter.

The implication from this study is that when characterising the influence of grazing on soils, the above and below-ground biomass in the vegetation should be analysed as well as the nutrient and organic matter content of soil. It appears that in this humid environment initial ecosystem changes in response to removal of grazing can be expressed in the vegetation, including litter and roots, without any marked effects on soil. Determining the nature and magnitude of these changes requires that both vegetation and soils be sampled and analysed. It is also clear that further work on appropriate soil indicators and sampling strategies (sample numbers, timing of sampling), and the time scales over which these indicators can be expected to change, is required before general recommendations for monitoring the sustainability of land use and determining the impact of grazing on the soils of unimproved tussock grasslands can be made.

Conclusions

Vegetation recovery inside the exclosures was not consistently reflected in mineral soil differences. At both sites there were few significant differences in soil tests between the exclosure and the surrounding grazed area, despite vegetation recovery which is particularly marked at Starvation Gully. The contrast in trends suggests differences in the partitioning of nutrients and organic matter between vegetation and soil at the two sites. Microbial C and the ratio of microbial C to total C did not show consistent clear trends indicative of the recovery of organic matter following cessation of grazing. The results clearly suggest a slow rate of change of soil properties associated with grazing in this humid environment and the need to sample soils, litter and vegetation when determining trends in organic matter and fertility.

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