Monitoring the effects of pastoral use on upland and high country soils in South Island, New Zealand

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Abstract

This paper reports on chemical changes that have occurred since 1978 in topsoils (O-7.5 cm depth) of upland and high country farms at 3 sites: Longslip and Glencairn Stations near Omarama, north Otago, and the east Otago uplands between Middlemarch and Alexandra. Between 1978 and 1992 on Longslip, on fertilised and oversown hilly and steep slopes, mean soil organic C increased by 67%, total N value changed little, and pH declined by 0.41 units. Associated with the soil changes were declines in the amount of bare ground and snow tussock cover, and increases in legume and hieracium cover. The organic C change was equivalent to an increase of about 11 t C/ha between 1978 and 1992. Over the same time period no topsoil changes on lower landscape positions were apparent. On Glencairn, under grazing but no topdressing, mean organic C declined by 10%, total N declined by 25% and pH declined by 0.43 units between 1978 and 1993. The organic C and N changes were equivalent to a decline of about 1.7 t C/ha and 0.4 t N/ha between 1978 and 1993. In contrast, within unfertilised and fertilised plots of exclosures that had not been mown or grazed for 9 years, organic C rose by 40-55%, total N rose by 21-36%, and there was no significant change of pH. Vegetation changes outside the exclosures included an increase of hieracium and briar cover. On the east Otago uplands under light grazing and little or no fertiliser application no significant changes of pH, organic C or total N were recorded between 1978 and 1994. The results show that soil monitoring can give useful information about the changes associated with pastoral use and the options available to maintain or enhance soil organic matter and pH levels.

Keywords: high country, monitoring, organic C, pH, sustainability, total N

Introduction

The 1970s and early 1980s were a time of agricultural development. However, the withdrawal of cheap loans and subsidies in the 1980s, concurrent with periodic explosions of rabbit populations and the invasion of weeds like hieracium and briar, has raised the issue of the sustainability of high country pastoralism (Hughes 1990). The ability of high country soils to support sustained pastoralism has been brought into question by O'Connor & Harris (1991) who calculated that 150 years of pastoralism has caused substantial losses of the four major nutrients (N, P, K, S) throughout the high country. The declining ability of soils to support productive pastures was a major issue shaping the recommendations of the High Country Review (Martin *et al.* 1994). Although assessments of soil changes are crucial to arguments about sustainability of pastoral land use, there have been few long- or medium-term studies of soil changes on individual farms. This paper reports on farm-scale soil changes since 1978 at three upland and high country locations.

Study areas and characteristics

The Longslip study area is a hilly and steep spur with strong aspect contrast at 685-l 190 m altitude south of the Ahuriri River. 25 km west of Omarama, North Otago. Mean annual rainfall is 700-1000 mm. Soils are Brown Soils and Pallic Soils previously mapped in the Kaikoura and Omarama sets.

The Glencaim study area is a hilly and steep spur with strong aspect contrast at 440-810 m altitude on the east side of the Benmore Range, 25 km north-west of Omarama. Mean annual rainfall is 500-600 mm. Soils are Pallic Soils previously mapped in the Meyer and Omarama sets.

The east Otago uplands study area is rolling land at 700-I 100 m altitude between Middlemarch and Alexandra, and has a rainfall of about 700-I 100 mm. Soils are Brown Soils previously mapped in the Teviot set.

Precise locations and characteristics of the study areas are given by McIntosh et al. (1981) and McIntosh & Backholm (1981). NZ Soil Bureau (1968) gives the general soil pattern at each location and McIntosh *et al.* (1981, 1983) describe the soils in detail.

In 1980 the Longslip area was oversown with clovers and grasses and between 1980 and 1992 a total of 1100 kg/ha of S-superphosphate (28% total S) was applied. The Glencaim area soils have not been oversown or topdressed. On the east Otago uplands'the amount of fertiliser applied is not accurately known but the presence of clovers at only one site in 1978 but at 11 of the 26 sites revisited in 1994, indicates that at these sites light topdressing, probably at the rate of about 250 kg/ha of single superphosphate (a standard initial rate for legume establishment), has occurred at least once.

No lime has been applied on Longslip or Glencairn and is most unlikely to have been applied on the east Otago uplands, where it is standard practice to spread lime only after cultivation.

Methods

On both Longslip and Glencairn, soils were grid sampled (O-7.5 cm depth) on slopes with strong aspect contrast. Stock camps were avoided. There were 38 sites on Longslip and 24 sites on Glencaim. At most sites soils were sampled in 1978, but a few were sampled in 1979. The same sites were resampled in 1992 and 1993 on Longslip and in 1993 on Glencaim. Details of sampling method are given by McIntosh *et al.* (1981, 1994).

On Glencaim stock- and rabbit-proof fertiliser trial areas (McIntosh *et al.* 1985; Boswell & Swanney 1990) have effectively functioned as exclosure plots since 1979. Trial plots were oversown in 1979 and mown (with clippings discarded) between the 1979 and 1984 seasons but afterwards not mown or grazed. Unfertilised control plots and plots fertilised twice with 370 kg/ha of S-superphosphate (27% total S) were sampled in 1993 for the present study.

On the east Otago uplands 26 sites near the Old Dunstan and Lake Onslow Roads were sampled in 1978 and 1994 by the methods described by McIntosh & Backholm (1981).

Soils were analysed by standard methods used at Invermay Agricultural Centre. Longslip 1993 samples were analysed for pH only. Differences in soil chemistry values between 1978 and 1992/93/94 sampling dates were analysed by paired t-test.

Longslip and Glencaim sites were sampled for bulk density in 1994 so that soil changes could be estimated on a weight per hectare (kg/ha) basis. Bulk density was calculated from the weight of oven-dried (1 10°C) O-7.5 cm soil, after removal of roots and stones (>2 mm), bulked from 30 cores of known volume from each of the 62 sites. Because soil bulk density was not measured in 1978, changes of organic C and total N on a weight per hectare basis were estimated by applying 1994 bulk density values for each site to both 1978 and later soil analyses.

Results

Soil chemical changes are summarised in Figure 1.

On Longslip the pH, organic C and total N changes since 1978 were described by McIntosh et *al. (1994).* Organic C increased significantly ($P<0.001$) by 67% (from 3.3% C to 5.5% C) between 1978 and 1992, the increase being larger on sunny slopes than on shady slopes. The small overall increase of total N over this time period was not significant ($P<0.05$) but there was a significant ($P<0.01$) 13% decline of total N on shady slopes and a significant ($P<0.05$) 26% increase of total N on sunny slopes. pH declined significantly ($P<0.001$) by 0.41 units, from 5.81 to 5.40, the pH decline being similar on both aspects. These soil changes were associated with a decline in the amount of bare ground and snow tussock cover, and an increase in legume cover and sites with hieracium (McIntosh *et* al. 1994). In contrast, at 7 sites on lower landscape units under similar management, there was a slight decline of organic C and total N and no change in pH (McIntosh *et al.* 1994).

Mean bulk density on Longslip was 0.69 t/m^3 on both sunny and shady slopes. The organic C changes are equivalent to an organic C increase of about 11 t/ha (from 17 t/ha to 28 t/ha) between 1978 and 1992, the increase on sunny slopes (15 t/ha) being greater than the increase on shady slopes (6 t/ha). The total N changes are equivalent to a total N increase from 1.4 t/ha to 1.7 t/ha on sunny slopes and a total N decline from 1.4 t/ha to 1.2 t/ha on shady slopes. (All values are approximate because bulk density was not measured in 1978.)

On Glencaim mean organic C was 2.3% in 1978. Under grazing but *no* topdressing (+G-F in Figure 1) organic C declined significantly ($P<0.01$) by 10% between 1978 and 1993. The decline was larger on sunny slopes (20%) than on shady slopes (4%). so that 1993 organic C was 1.5% on sunny slopes and 2.6% on shady slopes. Total N declined significantly ($P<0.001$) by 25% over this time period, from 0.24% N to 0.18% N, the percentage decline being similar on both sunny and shady slopes. pH declined significantly ($P<0.001$) by 0.43 units, from 6.30 to 5.87. In contrast, within exclosures that had not been cut or grazed for 9 years (-G+F and -G-F in Figure 1), there was no significant ($P<0.05$) change of pH on fertilised or unfertilised

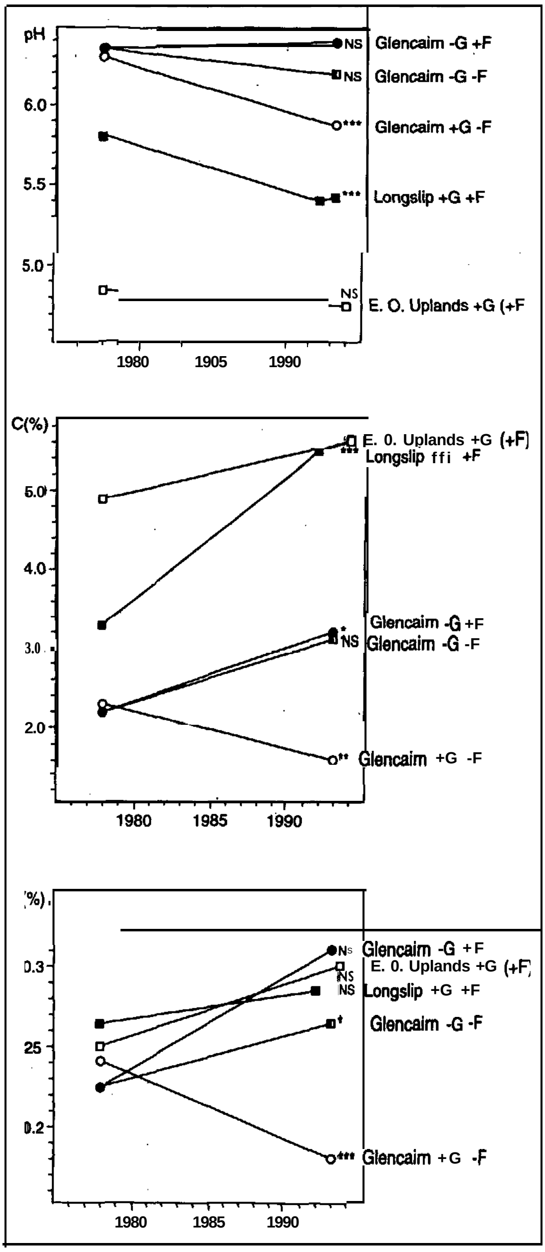

Figure 1 Mean changes of pH, organic C and total N in topsoils (O-7.5 cm). For clarity, points are linked by straight lines, but changes may not have been linear. +G = with grazing; -G = no grazing for 9 years; +F = with fertiliser (S+P plots as described in text); (+F) light topdressing at some sites; -F = no fertiliser. Significance levels relate to differences between 1978 and 1992, 1993, or 1994 values within treatments linked. by lines: * = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$; NS = not significant.

plots, organic C rose by 40-55%, and total N rose by 21-36%, but only the N rise on -G-F plots and the C rise on -G+F plots was significant ($P<0.05$).

Soil changes outside the exclosures were associated with an increase in the proportion of hieracium and briar cover (R.B. Allen, unpublished data). Soils under hieracium patches were on average more acid by 0.5 pH unit than soils under native vegetation sampled on the same date (McIntosh & Allen 1993).

Mean bulk density on Glencaim was 0.94 t/m^3 (1.04 t/m^3 on sunny slopes, 0.84 t/m^3 on shady slopes). The organic C changes are equivalent to an overall organic C decline from 15.8 t/ha to 14.1 t/ha between 1978 and 1993, the decline being greater on sunny slopes (2.7 t/ha) than on shady slopes (0.7 t/ha). The total N changes are equivalent to a total N decline from 1.8 t/ha to 1.4 t/ha on shady slopes and a decline from 1.4 t/ha to 1.1 t/ha on sunny slopes. (As previously mentioned, values are approximate.)

On the east Otago uplands mean pH of soils was 4.66 in 1978 and 4.74 in 1994, organic C increased from 5.1% in 1978 to 5.9% in 1994. and total N rose from 0.25 to 0.30%, but no difference was significant ($P<0.05$).

Discussion

Longslip

McIntosh et al. (1994) found that the pH declines noted on Longslip were approximately those to be expected from regression equations relating pH decline to amount of dry matter produced and the rate of elemental S applied (McIntosh et *al.* 1985). Linear regression of pH change against organic matter change implicated organic C accumulation in the process of pH decline on Longslip. pH decline could also be occurring through the process of N leaching (Sinclair et al. 1994).

The increase of soil organic C is attributed largely to the much greater dry matter production of fertilised pastures compared to production in unimproved pastures and reduced organic matter mineralisation under the improved vegetation cover. (The fertiliser rates used on Longslip would result in dry matter production approximately five to ten times higher than production from non-fertilised pastures.) The only alternative means for increasing organic carbon inputs to topsoil would he greater dry matter production as a result of higher rainfall, but the mean annual rainfall in the Ahuriri valley in the 7 years up to and including 1978 was 788 mm, only slightly less than the mean of 832 mm in the seven years up to and including 1992, and both these figures are below the 898 mm mean for this rainfall station. Therefore a significant rainfall. influence on 1992 organic C values on Longslip is discounted.

The organic C increase and less bare ground (than in 1978) on Longslip will aid moisture retention and provide greater resistance against erosion. The decline of total N on shady slopes possibly indicates transfer of N from shady slopes to stock camps.

Glencairn

The Glencaim data indicate that grazing alone (without fertiliser additions) affects topsoil chemistry, with sunny slopes being more prone to change than shady slopes. That organic C on Glencaim has declined to less than 2% in topsoils on sunny slopes indicates that these soils may now be more prone to degradation by wind and sheet erosion. We note that sunny slopes have organic C below the 2.5% minimum level for soil 'health' suggested by Parshotam & Hewitt (1994).

Organic matter removal by grazing animals is considered to be a major influence on C and N values on Glencaim. The results from exclosures (Figure 1) show that eliminating grazing by sheep and rabbits arrests organic C and total N decline, but that to lift organic C and total N fertiliser application will be necessary. Whether organic C and total N would increase on Glencaim if pastures were to be grazed as well as fertilised could not be ascertained from the data collected, but the Longslip data indicates this might be so, in which case the restoration of organic matter can proceed with grazing. However, economic analysis indicates that, given present returns from wool, fertilising and oversowing the hilly and steep land on Glencaim to increase production is unprofitable.

The pH decline is attributed partly to a net cation loss through grazing, either by transfer of cations off the farm in animal products or to stock camps within the farm. Decline of exchangeable cations since 1978 has been established (Landcare Research, unpublished data). Locally hieracium also depresses pH (McIntosh & Allen 1994).

East Otago uplands

The limited sampling and analyses undertaken on the east Otago uplands indicate that soil changes over the last 16 years in this area have been slight. However, during sampling it was noted that hieracium cover (estimated visually) had increased and tussock cover had declined, and further vegetation and soil monitoring is advised before the sustainability of present farm practices is assumed.

Conclusion

The results show that soil monitoring can give useful information for assessing the sustainability of high country pastoralism and future options. Long-term monitoring on other sites with contrasting pastoral management is required to establish whether the reported trends are more widespread.

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