Effects of human disturbance and cryoturbation on soil iron and organic matter distributions and on carbon storage at high elevations in the Cairngorm Mountains, Scotland

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Abstract

Soil profiles were sampled at 43 sites on granitic parent material at altitudes ranging from 970 to 1300 m in the Cairngorm Mountains, Scotland. Many soils under undisturbed vegetation showed evidence of iron and organic matter translocation with distinctive Bh or Bs horizons. Approximately 50% of the sites sampled had no or partial vegetation cover, due either to human activity (trampling) or active geomorphic processes such as cryoturbation on patterned ground. Exposed cols and summit ridges were most heavily affected by trampling with extensive areas of path development and some erosion. Trampling was principally associated with loss of the upper soil horizons and cryoturbation processes with disturbance of horizon development. Median total organic matter at the vegetated sites ranged from 4.8 to 22.0 kg m\(^{-2}\) with a median of 9.5 kg m\(^{-2}\). There was significantly less total organic matter at the unvegetated sites with median of 4.6 kg m\(^{-2}\) and range from 1.5 to 11.9 kg m\(^{-2}\). There was little difference in total organic matter between sites where vegetation disturbance was due to human trampling or to cryoturbation.

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1. Introduction

Alpine soils are usually excessively drained, coarse textured and stony (Retzer, 1974). Profile differentiation is affected at many sites by continuing
geomorphic processes such as solifluction and cryoturbation. These processes have been shown to result in features such as buried horizons and distortion of micromorphological features such as silt cappings (Elliott, 1996; Bockheim and Tarnocai, 1998). Additions of aeolian material, sometimes from long distances, contribute to soil mineralogy (Dahms, 1993) and base saturation (Bockheim and Koerner, 1997). Total carbon storage in alpine soils (Bockheim and Koerner, 1997) is relatively small when compared to that in temperate latitude soils generally (Batjes, 1996), but values are within the range of those found in arctic soils (Michaelson et al., 1996). Carbon storage in alpine soils may be particularly sensitive to changes in climate, as the duration of lying snow and summer temperature are significant controls of carbon dioxide flux from such soils (Jones et al., 1998; Williams et al., 1998).

In north-eastern Scotland, alpine soils are often podzolic in character (Romans et al., 1966), but there is also significant disturbance due to current geomorphic activity (Ballantyne, 1991). Such soils are also susceptible to trampling damage by the increasing numbers of visitors to mountain areas (Watson, 1991). Despite the fact that the upland areas of Scotland account for over 75% of carbon storage in UK soils, principally in peat soils (Howard et al., 1995), there are no published estimates of carbon storage in alpine soils or of the effects of disturbance on soil carbon.

The overall aim of this paper is to assess the extent and controls of soil development and soil carbon storage on the high plateau of the Cairngorm Mountains in north-eastern Scotland. The study was part of a larger investigation of the geomorphological sensitivity of the Cairngorm plateau. This paper will specifically examine the distribution of organic matter (OM) and free iron in soil profiles, quantify carbon storage in the soils and assess the impacts of human disturbance and cryoturbation on soil development and carbon storage.

2. Materials and methods

Forty-three soil profiles on the high plateau of the Cairngorm Mountains (Fig. 1) were sampled in the summer of 1997. The altitude of the plateau ranges from 950 to over 1300 m and the underlying geology is granite. Soils on the plateau have been mapped by the Soil Survey of Scotland as alpine podzols of the Countesswells association derived from granitic drift. Mean annual temperatures are 0–1°C and precipitation exceeds 2000 mm a⁻¹ (McClatchie, 1996). Vegetation (Ratcliffe, 1977) includes Nardus stricta grassland, Juncus trifidus heath, species-poor Rhacomitrium heath, Empetrum nigrum-Rhacomitrium heath and species-poor Deschampsia flexuosa grassland.

The soil sampling sites (Fig. 1) included a range of topographical situations, exposed cols (12 sites), north-trending spurs (12 sites), summit ridges (six sites) and high altitude hollows with the potential for snow accumulation (13 sites).
Fig. 1. Locations of sampling sites on the Cairngorm plateau.
These sites were further subdivided according to whether the vegetation cover was complete. The causes of vegetation disturbance varied. Summit ridge and col sites had evidence of significant path development. Cols also had evidence of cryoturbation in the form of stone stripes. Spurs and valleys had little evidence of path development and vegetation disturbance was principally due to cryoturbation, with hummocks, terracettes and stone polygons in the valleys and boulder lobes on the spurs. Effects of human disturbance were also assessed by comparing sites on three different parts of the plateau which were separated by deep glacial troughs (Fig. 1). Thirteen profiles were sampled in the most remote area (Ben Avon), only accessible by a 20-km walk from the nearest public road. Seventeen profiles were sampled on the Braeriach plateau which had intermediate accessibility. Thirteen profiles were sampled on the Cairn Gorm/Ben Macdui plateau, easily accessible by chair-lift from a car park.

Soil profiles were dug at each site and samples were obtained from all horizons for laboratory analysis. Sample volume was determined in the field where possible. Air-dried samples were ground with a rubber pestle and sieved through a 2-mm sieve. The mass of stones (> 2 mm) was determined and percentage stone content calculated. Field moisture content was calculated on subsamples of the < 2-mm soil after drying at 105°C. Where sample volume was known, stone-free bulk density was calculated. Particle size distributions were determined by laser diffractometry (Beuselinck et al., 1998) following destruction of OM with H₂O₂ and ultrasonic dispersion. Soils were non-calcareous and mean clay content was less than 3% (Table 1), so OM was determined by loss on ignition at 850°C on oven-dry < 2 mm soil (Hesse, 1971). Free iron (amorphous and organic-bound forms) was extracted with potassium pyrophosphate at pH 10 (Bascomb, 1968). Iron concentrations in the centrifuged extracts were determined by flame atomic absorption spectrophotometry.

Total OM in each profile was calculated from OM content, bulk density and horizon thickness. Where bulk density was not measured, it was estimated from OM and stone content (Adams, 1973; Alexander, 1989). The regression equation used to estimate bulk density was:

\[ BD (\text{kg m}^{-3}) = 1020 - 16 \times \text{LOI} \% - 8 \times \text{Stone} \% \quad (r^2 = 0.61) \]

Although many previous studies have quantified the effect of OM on bulk density using non-linear equations (Grigal et al., 1989; Huntington et al., 1989), the majority of samples here had less than 10% OM and the linear equation was the best predictor. The slope of the relationship between OM and bulk density was less those in linear equations reported by Manrique and Jones (1991). In the present study, stone content was also an important predictor variable.

Data for most properties were normally distributed and comparisons between vegetated and non-vegetated sites and among the three plateau areas were made using one-way analysis of variance. However, loss on ignition, moisture and iron content were positively skewed and these were log-transformed prior to
Table 1
Summary soil horizon data

<table>
<thead>
<tr>
<th></th>
<th>All sites</th>
<th>Vegetated</th>
<th>Unvegetated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>204</td>
<td>110</td>
<td>94</td>
</tr>
<tr>
<td><strong>Stones %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>53.3</td>
<td>48.7 * *</td>
<td>58.7 * *</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>18.8</td>
<td>19.0</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>Clay %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.7</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.5</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Silt %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>24.6</td>
<td>24.4</td>
<td>24.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>12.0</td>
<td>12.0</td>
<td>12.1</td>
</tr>
<tr>
<td><strong>Sand %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>72.7</td>
<td>72.8</td>
<td>72.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>13.2</td>
<td>13.3</td>
<td>13.1</td>
</tr>
<tr>
<td><strong>Loss on Ignition %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6.2</td>
<td>8.4</td>
<td>3.5</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>8.5</td>
<td>10.9</td>
<td>1.7</td>
</tr>
<tr>
<td>log Mean²</td>
<td>4.4</td>
<td>5.8 * *</td>
<td>3.1 * *</td>
</tr>
<tr>
<td><strong>Moisture %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>19.3</td>
<td>27.3</td>
<td>10.0</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>28.6</td>
<td>36.6</td>
<td>7.4</td>
</tr>
<tr>
<td>log Mean²</td>
<td>12.6</td>
<td>18.7 * *</td>
<td>8.0 * *</td>
</tr>
<tr>
<td><strong>Free Fe %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.14</td>
<td>0.18</td>
<td>0.10</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.18</td>
<td>0.23</td>
<td>0.09</td>
</tr>
<tr>
<td>log Mean²</td>
<td>0.09</td>
<td>0.10 * *</td>
<td>0.07 * *</td>
</tr>
</tbody>
</table>

¹Mean of all horizons.
²Mean of log values, based on all horizons.
³Significant \( p < 0.05 \) difference between vegetated and unvegetated.

analysis of variance. When total OM within profiles was calculated, there was evidence of significant non-normality and non-parametric tests were used in comparisons of total OM in the soils. The significance level used in all statistical tests was \( p < 0.05 \).

3. Results

Table 1 presents means and standard deviations of soil properties for all horizons and separately for those from vegetated and unvegetated sites. Soils
were stony with mean stone content of 53%. The < 2-mm fraction was dominated by coarse particles with mean sand content of 73% and mean clay content less than 3%. Organic matter contents were generally small (log mean of 4.4%) and soils were dry at the time of sampling (summer), with overall log mean moisture content of 12.6%. Moisture content was very closely correlated with OM ($r^2 = 0.9$). Free iron concentrations were low (log mean of < 0.1%).

Soils at unvegetated sites had significantly greater stone content and significantly smaller OM, free iron and moisture contents than vegetated sites. The differences for loss on ignition and moisture were particularly marked with unvegetated soil horizons having around half the OM and moisture contents of vegetated soil horizons. There were no significant differences among soil properties when compared among the three plateau areas for either vegetated or unvegetated sites.

Figs. 2 and 3 show the distribution of OM and free iron, respectively with depth for two soil profiles from each topographic situation sampled in each of the three plateau areas. One profile of each pair was located in an area of incomplete vegetation cover and the other was located in a vegetated area nearby. Organic matter distributions had surface maxima ranging from 2% to over 60% on the Cairn Gorm and Braeriach plateaux and to almost 40% on the Ben Avon plateau. There was evidence at some profiles of a subsurface increase in OM at depths of 20–50 cm (A7, A9, A10, A11, B1, B2, B8, C1, C6, C9 and C10). There was also clear evidence of iron redistribution within several of the profiles in all three plateau areas and the horizons with the clearest evidence of iron accumulation were the same as those noted above with a secondary maximum of OM.

Overall, there was a statistically significant difference (Mann–Whitney test, $p < 0.05$) in the total soil OM between profiles at vegetated and disturbed sites. The median total OM at the vegetated sites was 9.5 kg m$^{-2}$, more than twice the median of 4.6 kg m$^{-2}$ at the unvegetated sites (Table 2). There were no significant differences among these totals when the data were compared among the three plateau subdivisions. Table 2 also shows the results of comparisons of total OM in the profile between vegetated and unvegetated sites for each topographic situation. Median OM in the unvegetated profiles was significantly less than that in vegetated profiles for all four topographic situations.

3.1. Cols

Cols on all three plateau areas were very exposed with much evidence of wind action and there was also significant path development and trampling pressure on the cols and their side slopes. Altitude ranged from 980 to 1150 m, lowest on the Ben Avon plateau. The col on the Cairn Gorm plateau had
Fig. 2. Distribution of OM with depth (D) in selected soil profiles.
Fig. 3. Distribution of pyrophosphate-extractable Fe with depth (D) in selected soil profiles.
Table 2
Median and range of total soil OM at vegetated and unvegetated sites in each topographic situation

<table>
<thead>
<tr>
<th>Topographic Situation</th>
<th>Vegetated sites</th>
<th>Unvegetated sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sites</td>
<td>9.5 ± 4.8</td>
<td>4.6 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>4.8–22.0</td>
<td>1.5–11.9</td>
</tr>
<tr>
<td>N = 21</td>
<td></td>
<td>N = 22</td>
</tr>
<tr>
<td>Cols</td>
<td>10.4 ± 5.6</td>
<td>5.6 ± 2.7</td>
</tr>
<tr>
<td></td>
<td>7.2–12.8</td>
<td>2.7–8.9</td>
</tr>
<tr>
<td>N = 4</td>
<td></td>
<td>N = 8</td>
</tr>
<tr>
<td>N-trending spurs</td>
<td>11.1 ± 5.3</td>
<td>4.5 ± 2.1</td>
</tr>
<tr>
<td></td>
<td>5.3–19.6</td>
<td>1.5–11.9</td>
</tr>
<tr>
<td>N = 5</td>
<td></td>
<td>N = 7</td>
</tr>
<tr>
<td>Valleys</td>
<td>9.2 ± 3.2</td>
<td>3.2 ± 2.1</td>
</tr>
<tr>
<td></td>
<td>4.8–22.0</td>
<td>3.2–8.0</td>
</tr>
<tr>
<td>N = 10</td>
<td></td>
<td>N = 3</td>
</tr>
<tr>
<td>Summit ridges</td>
<td>10.8 ± 3.8</td>
<td>3.3–9.5</td>
</tr>
<tr>
<td></td>
<td>10.4–11.2</td>
<td></td>
</tr>
<tr>
<td>N = 2</td>
<td></td>
<td>N = 4</td>
</tr>
</tbody>
</table>

* Median.
† Range.

A *J. trifidus* dominated vegetation community and those on the other two plateaux had mixed *Rhacomitrium* and *J. trifidus* heath.

At vegetated site A9 on the Ben Avon plateau, OM decreased from the surface to about 50 cm, but there was a second maximum at 55 cm (Fig. 2). The semi-vegetated site A10, located 1 m from A9, lacked the surface organic horizon but also showed an increase in OM content at 40 cm in the subsoil. Iron distributions (Fig. 3) were similar, with evidence of an illuvial horizon coincident with the OM peak, but with a thinner eluvial zone. Site B1 on Braeriach was vegetated and within 20 m of the partially vegetated B2 site. B1 had a distinct surface organic horizon and evidence of illuvial OM and iron. B2 was thinner and had less OM at the surface but there was a clear illuvial organic horizon (Fig. 2). On the Cairn Gorm plateau, profile C4 (vegetated) was located within 20 m of C3 (partially vegetated with evidence of deflation). Profile C4 had a pronounced surface organic horizon, with 15% OM compared to less than 5% at C3 (Fig. 2) and clear evidence of iron redistribution within the profile (Fig. 3). Overall, vegetated profiles had iron and OM distribution typical of alpine podzols, with clear evidence of surface organic horizons and illuvial horizons enriched in both free iron and OM. All partially vegetated and bare sites showed evidence of truncation with the loss of the upper organic horizon. Total OM in the unvegetated profiles was significantly less than that in the vegetated profiles, with median value about half (Table 2).
3.2. North-trending spurs

Sites on spurs on the Ben Avon and Braeriach plateaux were above 1150 m altitude while those on the Cairn Gorm plateau were slightly lower (970–1040 m). Vegetation was generally species-poor *Rhacomitrium* heath, with *E. nigrum* a significant component on the lower Cairn Gorm sites and *J. trifidus* on the Ben Avon spur. Geomorphologically, sites were on blockfields, stone stripes or boulder lobes, with very little evidence of path development.

The OM distribution at vegetated site A12 showed a surface maximum of 9%, decreasing down profile (Fig. 2). At A11 (partially vegetated) the surface OM was less, but increased to a peak of 7% at 17 cm (Fig. 2). Organic matter content was less than 3% and evenly distributed throughout the thinner profile at a nearby bare site. At site B14 (vegetated blockfield on Braeriach) there was a pronounced decrease in OM (Fig. 2) and free iron (Fig. 3) with depth. At unvegetated site B10, located in an area of active stone stripes on the same spur, the soil had less OM in the surface horizon and there was a uniform distribution of iron and OM with no evidence of leaching. The vegetated site C6 on Cairn Gorm was thinner than those on the other two plateaux, but OM in the surface horizon was 65%, and with a slight secondary maximum at 14 cm (Fig. 2). This latter depth was also the horizon of maximum iron concentration (Fig. 3). At the nearby unvegetated site C7, OM and iron distributions were relatively uniform with depth and concentrations were much smaller with OM < 5% and Fe < 0.1%.

Overall, some of the soils sampled within this site type showed evidence of podzolisation, but most profiles lacked clear illuvial iron or OM horizons. Unvegetated soils were generally thinner than vegetated soils, OM and iron were well mixed throughout the soil profile and OM percentages were much smaller. Median total OM in the unvegetated soils was less than half that in the vegetated soils (Table 2).

3.3. Summit ridges

The summit ridge sites were very exposed with evidence of deflation but also extensive path development. The dominant plants were *J. trifidus* or *Rhacomitrium* spp. Altitudes ranged from just under 1200 m to 1300 m near the summit of Ben Macdui. No summit ridge sites were sampled on the Ben Avon plateau.

Vegetated sites had thin surface organic horizons as exemplified by site C9 at 1300 m (Fig. 2). The nearby site C8 on a bare trampled area had no surface organic horizon and appeared truncated. C9 also had some evidence of an illuvial iron horizon, absent from C8. The soils sampled on the summit ridge on Braeriach were slightly deeper, but the bare site was again truncated. There were again significant differences in total OM, with 10–11 kg m$^{-2}$ OM in the
vegetated profiles and a median of just under 4 kg m$^{-2}$ at the bare sites (Table 2).

3.4. Plateau valleys

Most sites in this group were dominated by snow-bed *N. stricta* grassland, although two slightly more elevated sites (B8 and A1) had *J. trifidus* heath. Altitude of the sites ranged from 1010 to over 1200 m. Vegetation disturbance was largely due to cryoturbation, with evidence of active patterned ground and little path development.

Vegetated site A7 on a terracette had a relatively small organic horizon content at the surface but the distribution of OM and iron provided clear evidence of translocation (Fig. 3). At A2, located in an area of active stone stripes the soil was thinner and OM and iron concentrations were smaller. Profile B9 was sited in a densely vegetated snowpatch and B8 in a nearby bare area. B9 had a pronounced surface organic horizon (45%) and slight evidence of iron leaching. B8 had a lower OM concentration in the surface horizon and clear evidence of iron and OM redistribution (Figs. 2, 3). At a hummock on the Cairngorm plateau (C10) there was a pronounced surface maximum in the percentage OM (Fig. 2) and the iron distribution showed an eluvial/illuvial horizon sequence. Site C1, in an area of active stone stripes, had a generally low OM content and no evidence of iron or OM leaching.

In the valley soils, there was significant evidence of podzolisation where soils had a complete vegetation cover. The greatest total OM contents were found in soils at sites with vegetation hummocks, with around 20 kg m$^{-2}$ OM and the least organic soils were found at the unvegetated sites where there was evidence of both truncation and mixing in the profiles. Differences between vegetated and unvegetated profiles were significant and median total OM at the unvegetated sites was about 35% of that at vegetated sites.

4. Discussion

There was significant evidence of soil profile development above 950 m altitude at most of the sites investigated on all three plateau areas. Where the vegetation cover was relatively complete, soils were alpine podzols (Soil Survey of Scotland, 1984) with clear evidence of Bh and Bs horizons (sites A7, A9, B1, C4 and C10). Romans et al. (1966) identified the illuvial horizon of colloidal humus from micromorphological evidence as one of the distinctive features of the soils in the alpine zone in north-east Scotland. These authors defined the horizon as an ‘alpine A’, but recognised that it had many characteristics of a Bh horizon as its colloidal humus had been translocated from an overlying A2 (E) horizon. Li et al. (1998) reported similar Bh horizons enriched in illuvial OM,
aluminium and iron at altitudes of 2400–2700 m in Taiwan. In the present study, alpine podzols were more commonly found in cols and snowpatch hollows, similar site types to those listed by Romans et al. (1966). Soil development on the very exposed summit ridges and on the boulder-covered spurs was much more limited.

Where the vegetation cover had been disturbed, either by trampling or by geomorphic activity, soils showed signs of disturbance. Disturbance included truncation in the form of loss of the upper organic horizon and mixing, evidenced by the absence of identifiable soil horizons and a uniformly low OM concentration with depth. Evidence of truncation was most clearly seen in the col and ridge sites. Path development was most evident at these sites and trampling is likely to be a significant trigger of truncation. However, these sites were also very exposed and wind action has probably exacerbated the removal of the surface soil horizon after the vegetation has been disturbed. Trampling was least evident in the snow patch sites. At these, bare ground was mainly due to cryoturbation and unvegetated soils were relatively uniform in their characteristics. There was no evidence of cyclical soil development in the form of buried organic horizons separated by wash layers at these disturbed sites, although, in some areas of active surface gravel movement, buried H or Ah horizons were observed.

Differences among soils on the three plateau subdivisions may also reflect the influence of human disturbance. Soils in the snowpatch hollows had the greatest accumulations of OM with approximately 20 kg m\(^{-2}\) at profiles in areas of vegetation hummocks. These sites had no evidence of surface disturbance, with a relatively undisturbed cover of *N. stricta* grassland. Snowpatch sites are usually wet in summer and avoided by walkers. No systematic differences among the three plateau areas were evident. In contrast, all three cols were the focus of well-trampled pathways with eroded areas on the slopes leading down into the cols and large areas of disturbed vegetation. Although there were no differences in OM in the disturbed sites on the three plateau areas, the vegetated Cairngorm site had the smallest total OM (7.2 kg m\(^{-2}\)). This may reflect trampling pressure as this site was very near the most heavily used footpath on the plateau (Watson, 1991).

Vegetation disturbance was associated with significant reductions in total OM in the soil. Unvegetated soils had less than half the total OM of vegetated soils. Such differences were found in all four site types. This suggests that the effects of human-induced disturbance on total soil OM in the most heavily trampled sites on the cols and summit ridges are of a similar magnitude to the effects of cryoturbation processes seen in the least trampled snowpatch sites. If the standard 58% ratio is used to convert OM to carbon (Batjes, 1996), total carbon storage in these alpine soils ranged from 0.7 to 12.8 kg C m\(^{-2}\). The mean values of 6.5 kg C m\(^{-2}\) for vegetated soils and 3.0 kg C m\(^{-2}\) for disturbed soils are small in the UK (Howard et al., 1995) or global (Batjes, 1996) terms. The values
reported here are, however, similar to those in alpine soils in North America. Carbon storage in soils on quartzite at elevations of 3400–3700 m in Utah ranged from 3–22 kg m$^{-2}$ (Bockheim and Koerner, 1997). For soils in Alaska at altitudes of 900 to 1250 m, Michaelson et al. (1996) found carbon storage ranging from 3 to 16 kg m$^{-2}$.

5. Conclusions

Evidence of significant soil development was found in all three areas of the high Cairngorm plateau, even at sites with current geomorphic activity or with vegetation disturbance caused by human activity. Soil depths were commonly in excess of 50 cm and some horizons had large percentages of OM and free iron. At many sites there was also evidence of translocation of these substances within the profiles, which were generally podzolic in nature.

The soils are sensitive to disturbance. Where there was a concentration of trampling pressure, truncated profiles and a reduction in soil OM concentrations were found. Where cryoturbation processes were mainly responsible for disturbance, soil horizons were not well differentiated and OM was again reduced. Reduction in total OM in the disturbed soils were by more than half and the magnitude of the reduction was similar for human-induced and natural processes. Storage of organic carbon in the vegetated soils of the plateau was relatively small, much less than in the majority of upland soils in Scotland and closer to the quantities found in arctic and other alpine soils.

References