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Impacts of extensive grazing and abandonment on grassland soils and productivity

C.A. Marriott, J.M. Fisher, K. Hood, R.J. Pakeman*

Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH, UK

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ABSTRACT

Two long-term (16 year) experiments on intensively managed pastures compared extensive grazing, abandonment and continued intensive grazing and were assessed for impacts on soil parameters, plant nutrient content and ecological indicator values. There was a reduction in soil carbon and nitrogen in the abandoned treatment compared to the intensively managed treatment at the wetter site. At the drier site, extensive grazing resulted in a build up of soil carbon. There was a build up of dead organic matter and a reduction in the nutritive value of the vegetation as grazing was reduced. Indicator values confirmed the reduced soil nutrients and a fall in site pH. There was also a rise in the dominance of plants preferring moist conditions, especially at the wetter site.

As biodiversity gains are small, the management of these systems could be seen as a trade-off between managing for production and for soil organic carbon. At the drier site this trade-off is apparent, whereas at the wetter site managing for production also maximises soil carbon content.

1. Introduction

Intensively managed grasslands are generally depauperate in terms of their biodiversity (Firbank, 2005). Consequently, there have been considerable efforts within the European Union to reverse biodiversity losses (Kleijn and Sutherland, 2003) and to build more sustainable farming systems (Commission of the European Communities, 2001), by paying farmers to reduce stocking rates and fertiliser inputs. Payments have been aimed at producing more extensive farming systems as it is acknowledged that abandonment of many agricultural systems is detrimental for biodiversity (MacDonald et al., 2000; Poschlod et al., 2005).

However, there maybe trade-offs between managing for biodiversity and managing for ecosystem services such as soil carbon (Marrs et al., 2007), and managing for the latter may be deemed more important by society in certain circumstances (Freibauer et al., 2004). However, within grazing systems it appears intensive management can result in an increase in net primary productivity (NPP), and this in turn leads to increased soil carbon stocks (Conant et al., 2001). Fertiliser used to increase NPP reinforces this, but there is a debate on the overall carbon budget with regard to fertiliser use as there are costs associated with making, transporting and applying it (Smith, 2008). Consequently, potential divergent societal goals for intensive grasslands exist and consideration has to be given to the trade-offs between services such as soil carbon sequestration and biodiversity. Similar arguments can be made for production services if extensive management results in system changes that are costly to reverse, though some of these systems have been shown to be capable of re-intensification (Marriott et al., 2003), and hence this may not be a major issue.

In light of these environmental and societal pressures, the impact of altering the grazing management of improved grasslands is important as they constitute a large part of the land cover of Europe, and specifically within the UK where they cover c. 5,067,000 ha or 21.1% of the land surface area (Carey et al., 2008).

The overall aim of this analysis was to understand the long-term (16 year) impacts of the removal of fertiliser inputs and reduced grazing/abandonment on site fertility and nutrient stocks through (1) monitoring of major soil chemical indices, (2) monitoring of biomass and biomass nutrient content and (3) monitoring of changes in plant indicator values (Ellenberg, 1988) related to soil properties.

2. Materials and methods

An experiment comparing sward responses in established ryegrass/white clover pastures under productive management and a range of more extensive management options was set up in 1990 at

* Corresponding author. Tel.: +44 01224 395001; fax: +44 01224 395010.
E-mail address: r.pakeman@macaulay.ac.uk (R.J. Pakeman).

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Table 1
Details of the experimental sites.

	Hartwood	Sourhope
Location	3°49′W, 55°49′N	2°14′W, 55°29′N
Altitude	245 m	367 m
Annual rainfall[a]	1265 mm	1057 mm
Soil type[b]	Stagnic gleyic cambisol	Umbric cambisol
Soil class	Non-calcareous gley	Brown forest
Drainage class	Imperfectly drained	Freely draining
Lime applied	1985	1982
Sward sown	1986	1981/2
Grazing history		
1989	Ewes and lambs, silage, lambs cattle and goats silage cuts then lambs	Ewes and lambs Ewes and lambs Ewes and lambs
1988		
1987		
Pre-experiment fertiliser history		
1989 (kg ha^{-1} of NPK)	139, 6.6, 12.5	113, 11, 21
1988	173, 21, 40	113, 11, 21
1987	260, 24, 46	113, 11, 21

[a] Rainfall data are 10-year averages from local weather stations.
[b] World Reference Base (WRB), FAO, Rome.

two upland sites in Scotland (c.f. Marriott et al., 2009 and Table 1). There were four treatments, each replicated twice, at each site: (1) productive management, i.e. fertilised annually in March and August with 50 kg N ha^{-1} as ammonium nitrate and in May with a compound fertiliser supplying 40, 8.7, 16.6 kg N, P and k ha^{-1}, and maintained at a sward surface height of 4 cm from March until mid-November (4F); (2) an unfertilised, grazed treatment maintained at 4 cm over the same period (4U); (3) an unfertilised, grazed treatment maintained at 8 cm over the same period (8U); (4) no fertiliser applications and no grazing (UN).

Each treatment plot was approximately 0.45 ha. The grazed treatments were maintained with different mean sward surface heights by adjusting the number of sheep on each plot after weekly measurements of sward height (Barthram et al., 2002). Grazing was with Scottish Blackface ewes and single lambs (until weaning in mid-August). Since there were site differences in plant growth, the number of livestock required to maintain the sward height treatments varied (Marriott et al., 2009). The reduction in the numbers of ewes on the unfertilised treatments relative to treatment 4F was similar at both sites. At Hartwood the 4U treatment held 68.4% of the animals of the 4F, and the 8U 41.6%. At Sourhope these figures were 64.8% and 38.5%, respectively.

2.1. Soil and biomass sampling and chemical analyses

Soil samples were collected from all plots on two occasions in each year from 1991 to 2006: in March, before the grazing season began, and in November, at the end of the grazing season. A single composite sample was taken from each plot (30 auger samples to a depth of 15 cm from a random 'W' walk). Soil samples were air dried at 30 °C and ground to pass a 2 mm mesh. Soil pH was analysed using a ratio of 15 g soil to 45 ml deionised water. It was also analysed after adding 5 ml 0.1 M $CaCl_2$ (McLean, 1982); this gave essentially the same pattern and is therefore not reported on. Soil total C and N content was determined by an automated Dumas combustion technique using a Flash EA1112 Elemental Analyser (ThermoFinnigan, Milan, Italy). Total P was determined using a sodium hydroxide fusion method (Smith and Bain, 1982) and colorimetric analysis. Exchangeable cations (Ca, K and Mg) were extracted using neutral 1 M ammonium acetate and determined using inductively coupled plasma optical emission spectroscopy (ICP-OES) (Thomas, 1982).

Vegetation samples were cut to ground level from 0.2 m × 1 m quadrats in July each year. Four samples were taken from each plot on each occasion, with each sample taken at a randomly selected position in each quarter of each plot. Samples were stored at −18 °C until separation of subsamples to determine composition by weight. All subsamples were separated into live and dead, and moss was separated from the live material. All plant material was dried overnight at 60 °C. The total vegetation dry mass (DM ha^{-1}), the DM of each category separated and its proportion relative to total DM were calculated. Dried plant material was ball-milled, and samples were digested by the Kjeldahl method (Wall et al., 1975) and analysed for N content using a segmented flow analyser, and P and K contents using ICP-OES.

Ellenberg (1988) weighted indicator values, recalculated according to Hill et al. (1999, 2000) were used for F (moisture), L (light), N (nitrogen or general soil fertility) and R (reaction or soil pH).

2.2. Statistical analyses

As soil variables for each plot were recorded twice per year, differences between treatments were assessed using residual maximum likelihood. Fixed effects were season + treatment × time (treatment, time and their interaction), random effects were block + plot.time (interaction between plot and time elapsed since the start of the experiment), and the model for correlation within subject across time was a power model (city-block metric) of order 1. Residual maximum likelihood analysis was carried out using Genstat ver. 10.1 (Lawes Agricultural and Trust, 2007). Changes in herbage mass, chemical composition and Ellenberg scores were tested in the same manner except without the Season term in the fixed effect part of the model.

3. Results

3.1. Soil chemical analyses

At Hartwood soil pH showed a general decline across all treatments with time (Table 2) as the impacts of the original liming in 1985 declined (soil data shown in Fig. A1). The soil pH of grazed treatments was very similar, but that of the UN treatment was significantly higher. There was no evidence of any divergence (no significant time × treatment interaction) between the treatments as the experiment progressed. Soil pH was consistently higher in spring.

Loss on ignition (LOI) was relatively stable across most of the experimental period (Table 2), but there was a substantial fall at the end of the experiment in all treatments. LOI was significantly higher