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The impact of organic and inorganic fertilizers and lime on the species-richness and plant functional characteristics of hay meadow communities

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ABSTRACT

Vegetation responses to fertilizers and lime applied in a seven-year study at paired unimproved and semi-improved mesotrophic hay meadows in Cumbria and Monmouthshire, UK, are described in terms of species-richness and several other plant community variables. Treatments were farmyard manure (FYM) applied at rates of between 6 and 24 tonne ha^{-1} annually or every third year, inorganic fertilizers giving equivalent amounts of N, P and K, and lime applied either alone or with FYM applied annually or three-yearly. Annual FYM at 24 tonne ha^{-1} reduced species-richness and the richness of positive indicator species at all sites and increased the proportional cover of nutrient-demanding species, whilst liming in conjunction with 12 tonne ha^{-1} annual FYM application was equally detrimental at the unimproved site in Wales but not in Cumbria. Inorganic fertilizers were apparently no more detrimental to vegetation quality than equivalent FYM treatments, although medium-term nutrient supply from FYM may have been underestimated. Species-richness was maintained by FYM at $\leqslant$12 tonne ha^{-1} $year^{-1}$ in the semi-natural northern meadow, where such levels had been used in the past, but only by amounts equivalent to $\leqslant$6 tonne ha^{-1} $year^{-1}$ at the Welsh sites which had no recent history of fertilizer use. It is unclear to what extent such differences are attributable to innate differences in plant community type, rather than to site-specific differences in past management. The implications of our findings for defining sustainable fertilizer practices to maintain or enhance the nature conservation value of mesotrophic meadows are discussed.

1. Introduction

Increased use of artificial fertilizers is implicated in the wide scale decline in species-rich grassland across Europe (Ellenberg, 1988; Bakker, 1989; Berendse et al., 1992; Myklestad and Sætersdal, 2004). In the UK the loss of traditional hay meadows and other unimproved grasslands has been associated with severe declines in many once common plant and

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animal species (Ratcliffe, 1977, 1984; Fuller, 1987; Rich and Woodruff, 1996; Goulson et al., 2005).

Cynosurus cristatus–Centaurea nigra grassland, the MG5 community of the British National Vegetation Classification (NVC – Rodwell, 1992), is the most widespread lowland example of species-rich grazed hay meadow in the UK (Blackstock et al., 1999).The MG3, *Anthoxanthum odoratum–Geranium sylvaticum* grassland, is the characteristic grazed hay meadow of the upland fringes of northern England (Rodwell, 1992). MG5 grassland has close affinity to Atlantic and Sub-Atlantic Cynosurion grassland in Europe (Rodwell et al., 2007). MG3 grassland has clear affinities with meadows growing at higher altitudes throughout northern and central mainland Europe (Rodwell et al., 2007). MG3 communities are reliant upon the maintenance of traditional hay-making practices without the use of inorganic fertilizers (Smith and Jones, 1991; Smith and Rushton, 1994; Smith et al., 1996). The same management regime, in combination with seed addition, is important in the restoration of MG3 communities to semi-improved meadows (Smith et al., 2000, 2002). A combination of hay cutting and grazing is also the most common management of MG5 habitats, although some are managed by extensive grazing only (Rodwell, 1992; Crofts and Jefferson, 1999).

Use of farmyard manure (FYM) and occasional liming are traditional management practices for hay meadow communities (Smith, 1988; Simpson and Jefferson, 1996; Tallowin, 1998; Crofts and Jefferson, 1999; Jefferson, 2005). However, what constitutes sustainable practices to maintain the nature conservation value of some species-rich communities is ill defined.

Many studies have shown detrimental effects of inorganic fertilizers on species-rich meadow vegetation (e.g. Berendse et al., 1992; Mountford et al., 1993; Kirkham et al., 1996; Silvertown et al., 2006), but there has been no study in which FYM treatments have been matched with inorganic fertilizers supplying equivalent amounts of inorganic nitrogen (N), phosphorus (P) and potassium (K). Since changes in farming practice in the UK have reduced the availability of FYM, there is a need to ascertain if or when inorganic fertilizers can be sustainable alternatives.

Resolution of these questions is an important pre-requisite for the refinement of management guidelines for the conservation of biodiversity within existing species-rich, semi-natural plant communities within statutory sites and agri-environment schemes. The importance of defining sustainable management for restoring such communities to agriculturally improved grasslands is also recognized, both in the UK and in continental Europe (Ormerod, 2003). Improved grasslands (MG6 and MG7; Rodwell, 1992) are very common throughout the UK with close equivalents widespread in mainland Europe (Rodwell et al., 2007).

An experiment involving several FYM or matched inorganic equivalent fertilizer treatments, and treatments incorporating initial liming, with or without annual or intermittent (three-yearly) FYM applications, was established in 1999 on paired, unimproved and semi-improved lowland meadows in south-east Wales and in upland meadows in north-west England. Treatment effects on botanical composition were monitored annually to identify: (a) optimum amounts and frequencies of FYM for the maintenance or enhancement of vegetation quality; (b) any difference between the impact of FYM and equivalent amounts of N, P and K applied as inorganic fertilizer; and (c) any interaction between the use of FYM and lime inputs.

Preliminary agronomic and botanical results for 1999 and 2000 were reported elsewhere (Tallowin et al., 2002; Kirkham et al., 2002). This paper describes botanical responses over the period 1999–2005. Nomenclature of vascular plants follows Stace (1997), except for NVC community names which follow Rodwell (1992).

2. Materials and methods

2.1. Experiment sites

Experimental plots were established on paired agriculturally unimproved and semi-improved meadows at upland sites in Cumbria, North West England, and a lowland site in Monmouthshire, Wales. The Cumbrian unimproved site at Raisbeck was located about 1.5 km from the semi-improved site at Gaisgill in the Tebay-Orton area at 54°27' N and 2°34' W. The unimproved site in Wales, Pentwyn, was adjacent to the semi-improved site, Bush, with both being close to Monmouth at 51°46′ N and 2°41′ W.

Soils at the Cumbrian sites were clay–loam in texture, whilst those at the Welsh sites were a mixture of sandy silty loam to silty clay–loam. The Cumbrian soils were higher in total N, carbon, organic matter, extractable P and exchangeable K and sodium (Na), although the most striking difference was the high level of extractable P at Gaisgill compared with all the other sites (Table 1).

The vegetation of Raisbeck in 1999 (Kirkham et al., 2002) corresponded to the MG3b (*Anthoxanthum odoratum–Geranium sylvaticum* grassland, *Briza media* sub-community) of the NVC, whilst that at Gaisgill corresponded to MG7 grassland, in particular the MG7e (*Lolium perenne–Plantago lanceolata* grassland) (Rodwell, 1992). The vegetation of Pentwyn in 1999 corresponded to the MG5a (*Cynosurus cristatus–Centaurea nigra* grassland, *Lathyrus pratensis* sub-community) but with some similarities to the MG5c (*Danthonia decumbens* sub-community). The vegetation of Bush was closer to the MG5a and MG6 (*Lolium perenne–cynosurus cristatus* grassland) communities (Rodwell, 1992).

2.2. Past management

Raisbeck, Pentwyn and Bush meadows had previously been managed over a long period by cutting for hay. Gaisgill had also been cut for hay and occasionally for silage. Cutting occurred after 1 July at both Raisbeck and Gaisgill, and after the second week in July at Pentwyn and Bush in compliance with conditions imposed by the owner, Gwent Wildlife Trust. Raisbeck had received about 12 tonne FYM ha^{-1} each year, usually in late April, but occasionally in mid summer following the hay harvest, and had received periodic applications of lime (amounts not known), the last one in about 1993. Gaisgill had received inorganic fertilizers in March to late April, whereas FYM was generally applied in February to March. Prior to about 1979, Gaisgill had received much lower nutrient inputs.