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A role for liming as a conservation intervention? Earthworm abundance is associated with higher soil pH and foraging activity of a threatened shorebird in upland grasslands

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ABSTRACT

The relationship between farmland bird populations and agricultural intensification has been well studied. However, the impact of variation in soil conditions and soil management is an exception, especially in upland (sub-alpine) farming systems. In this study, we examined the relationships between liming history, soil pH and patterns of foraging by Northern Lapwing, *Vanellus vanellus*, chicks in order to test the potential utility of soil amendment as a conservation intervention for shorebirds nesting in agricultural grasslands. Limed fields had higher soil pH than unlimed fields, and soil pH declined with the number of years since a field was last limed. The most important predictor of total earthworm abundance was soil organic matter with very few earthworms in peats of very high organic matter content. However, there was a marked additive effect of soil pH with earthworms more than twice as abundant at high (pH 6.0) as at the low (pH 3.5) extremes of soil pH recorded in the study. Specifically, at Lapwing chick foraging locations, the density of *Allolobophora chlorotica*, an acid-intolerant species of earthworm found just below the surface of the soil, was significantly higher than at randomly selected locations. These results suggest that liming helped to maintain breeding habitat quality for Lapwings and other species dependent on earthworms. This is of conservation significance in upland agricultural grasslands in the UK, where there has been a long-term reduction in agricultural lime use since the mid-20th century. Field-scale trials of liming would be valuable to test whether targetted amendment of soil pH in agriculturally improved grasslands could retain an important role in conservation management for shorebirds in upland landscapes where geology, high rainfall, and leaching tend to acidify soils over time.

1. Introduction

Agricultural intensification has been implicated in widespread declines in biodiversity, with negative effects of agricultural change on birds in Europe particularly well documented (Robinson and Sutherland, 2002; Newton, 2004; Wretenberg et al., 2007; Wilson et al., 2009). Intensification has resulted in a simplification of the farmed landscape associated with reduced habitat heterogeneity and availability of nesting opportunities and food sources for many farmland birds (Benton et al., 2003; Tscharntke et al., 2005).

One aspect of agricultural change which has received relatively little attention in relation to farmland bird declines is soil management in upland (sub-alpine) grassland systems, and especially the amendment of soil pH. This is surprising because soil invertebrates provide important food resources for a wide range of farmland-feeding birds including shorebirds, thrushes, starlings and corvids (Tucker, 1992; Wilson et al., 2009), and the diversity and abundance of many of these invertebrate groups are pH-sensitive (Edwards and Bohlen, 1996; Cole et al., 2006).

Soil pH is reduced by agricultural processes such as cropping and the use of nitrogenous fertilisers, but also naturally through

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leaching of calcium and other base cations from the soil and has been further lowered in some areas by anthropogenic atmospheric acid deposition (Rowell and Wild, 1985). Natural leaching of calcium is faster in areas with higher rainfall, especially where acidic underlying geology and peat formation result in low buffering capacity. These conditions describe agriculturally marginal, upland grasslands over much of the UK. Such landscapes are now an international important stronghold for populations of breeding shorebirds of several species (e.g. Eurasian Curlew, *Numenius arquata*; Brown et al., 2015). Yet even in these environments, they are declining rapidly (Balmer et al., 2013; Brown et al., 2015) having already suffered catastrophic declines in lowland agricultural systems (Wilson et al., 2005; Lawicki et al., 2011).

The effects of soil acidification are widely counteracted through agricultural liming to raise soil pH (MAFF, 1969; Wilkinson, 1998; Spaey et al., 2012). In the UK, agricultural lime sales peaked in the 1950s and '60s under a Government subsidy which persisted into the 1970s (Fig. 1), but have since declined steadily to pre-subsidy levels. Low soil pH and declines in pH occurred between the 1970s and 2001, particularly in western and northern areas that are dominated by livestock farms in higher altitude, higher rainfall environments (Baxter et al., 2006). By 2007, there was some evidence that this trend was being reversed, perhaps due to the declining impacts of acid deposition from industrial pollution (Emmett et al., 2010).

Earthworms comprise around 75% of soil fauna biomass in temperate grasslands (Bardgett and Cook, 1998), play a key role in maintaining soil fertility and constitute a prey resource for a number of birds that are associated with farmland, including shorebirds, gulls and corvids (Barnard and Thompson, 1985; Wilson et al., 2009). Earthworms are sensitive to soil pH and very few earthworms occur in soils below pH 4.3 (Edwards and Bohlen, 1996). Because lime is applied as a surface dressing, it has a greater effect on epigeic and endogeic (surface and near-surface dwelling) than anecic (burrowing) earthworm species, with reported increases in earthworm abundance following liming being mainly in epigeic species (Deleporte and Tillier, 1999; Bishop, 2003; Potthoff et al., 2008). Accordingly, Brandsma (2004) identified an increase in field use by both Northern Lapwings *Vanellus vanellus* (henceforth "Lapwings") and Black-tailed Godwits *Limosa limosa* following increases in earthworm abundance that occurred after liming.

In this study we use upland agricultural grassland with a known liming history to test the impact of lime use on prey resources and foraging habitat use by Lapwings, for whom earthworms are an important component of the diet, including during chick development (Beintema et al., 1991; Sheldon, 2002). Specifically we addressed the following questions:

1) How long does the positive effect of liming on soil pH last?
2) How is earthworm abundance related to soil pH and other potentially important soil characteristics, moisture and organic matter?
3) Do locations selected by foraging Lapwing chicks have a higher abundance of epigeic or endogeic earthworms than randomly selected locations?

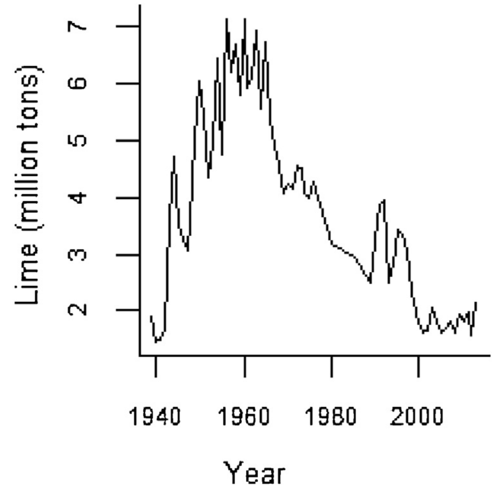

Fig. 1. The quantity of lime sold in Great Britain for agricultural purposes, annually since 1939: data sources: 1939–1976, Agricultural Lime Producers' Council (1977), 1980–1989, Wilkinson (1998), 1990–2000, Hillier et al. (2003), 2001–2013, Bide et al. (2015).

2. Methods

2.1. Study area

The study took place from 2009 to 2011 on upland grassland in central Scotland (56°4′40.06″N 4°0′45.00″W), covering three livestock farms (Townhead, Muirpark and Lochend) and a total area of 685 ha. The underlying geology is basalt, overlain by glacial tills, and peat. The average annual precipitation within the area is 1020 mm (Met Office; www.metoffice.gov.uk). The three farms all produce beef cattle and sheep and range from 140 m to 340 m above sea level. Field types in marginal agricultural areas such as this are split into two types; 'in-bye' (enclosed fields used for either arable or sown grass production), and 'out-bye' (semi-natural grass and dwarf shrub 'moorland' vegetation cover used for rough grazing only) (Gray, 1996).

2.2. Soil pH and earthworm sampling

Soil properties and earthworm abundance were assessed in 19 fields which had undergone differing numbers of lime application within the preceding 10 years (Table 1). Around 50 ha of the in-bye land at Townhead had been used to grow a brassica fodder crop in the preceding ten years (McCallum, 2012). This provided a contrast between fields that had undergone fodder crop management and had received two or three lime applications (5 t ha^{-1} annum^{-1}, applied as a surface dressing of fine pelleted magnesium lime) in the preceding 10 years, and fields that had not undergone this cropping management, and had received either no or just one lime application during this period. Because liming occurred at the time of fodder crop management and this was rotated round fields, the number of years since the last lime application varied between fields. In-bye fields at

Table 1
Mean ± standard error of field soil pH and organic matter (raw data) for each farm showing fields grouped by history of liming.

Farm	Field type	Lime applications in preceding 10 years	No. of fields	Mean soil pH	Mean soil organic matter (%)
Townhead	In-bye	2 or 3	6	5.1 ± 0.10	21 ± 3
Townhead	In-bye	0 or 1	7	5.0 ± 0.10	30 ± 2
Townhead	Out-bye	0	2	4.5 ± 0.33	33 ± 3
Muirpark	In-bye	0	2	4.6 ± 0.003	37 ± 1
Lochend	In-bye	1 or 2	2	5.3 ± 0.16	26 ± 5