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Can species-rich grasslands be established on former intensively managed arable soils?

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ABSTRACT

Land use change from intensive arable production to extensively managed grassland is encouraged through subsidy payments to farmers under the European Union's Common Agricultural Policy. Created grasslands are sown with a species-rich seed mix and receive limited or no fertiliser application, with the aim of increasing the provision of non-production ecosystem services. In the UK these agri-environment schemes are funded for periods of 5, 7 or 10 years. This study compared the plant diversity and soil properties of paired intensively managed (IM) arable and recently created (3, 5, 8 and 9 years) extensively managed species-rich grasslands (SRG) at 4 sites in the Scottish Borders. Botanical surveys of the newly created grassland plots showed limited establishment of the species-rich seed mixes and the dominance of grasses that favour more nutrient-rich environments. Soil properties at 0–10 and 30–40 cm depths were measured over 2 consecutive years. Total and available soil nitrogen, phosphorus and soil organic carbon were not significantly different between paired plots. This study suggests that the residual nutrients from previous fertiliser applications may prevent the establishment of species-rich seed mixes for up to a decade after land use change from intensive arable to extensive grassland management.
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1. Introduction

A growing awareness of the value of non-production ecosystem service (ES) provision to human health and wellbeing has encouraged the funding of agri-environment schemes in the UK, through which farmers receive funding to alter management practices to increase the provision of certain ES. In general, management to maximise production causes the decline of other ES (MA, 2005) including the regulation of water quality and nutrient cycling and maintenance of biodiversity, with mixed effects reported on climate regulation (Pilgrim et al., 2010). In the European Union (EU) direct support and subsidies are provided to farmers through the Common Agricultural Policy (CAP). Funding for environmental initiatives is provided under the second pillar of the CAP through the European Agricultural Fund for Rural Development (EAFRD) and includes agri-environment schemes that aim to enhance the environmental value of land, such as the extensification of agricultural management through the creation of semi-natural grasslands (EC, 2009). Under these schemes farmers are required to carry out an extensification of management practices by reducing or ceasing fertiliser application, grazing and cultivation, or removing the existing crop or sward and sowing a specified seed mix of desired grassland species. In England by the end of 2012 there were over 80,000 ha of created or restored grasslands (Wilson et al., 2013), and £3 million was spent on the creation of species rich grasslands and arable reversion to grassland in Scotland from 2008 to 2012 (Scottish Executive, 2012).

Across the UK, SRG creation schemes are funded for periods of between 5 and 10 years. Thus, within 10 years of adoption the benefits of agri-environment schemes aimed at enhancing the provision of non-production ES should justify both the loss of production and the cost of the financial subsidy awarded to farmers (Horrocks et al., 2014). Despite the commitment of substantial sums of money and land to extensification schemes, there has been little research into (i) the extent to which they enhance provision of multiple ES and (ii) the potential for the legacy of intensive agriculture to continue to limit ES provision during the funding period of the agri-environment scheme. The creation of SRG in Scotland is listed as a land management option under the 'biodiversity and landscape' and 'water quality' regional priorities (Scottish Executive, 2009), so the provision of increased biodiversity and improved water quality are key targets for SRG creation schemes. The UK is a signatory of the Convention on Biodiversity (CBD) and is obliged to take targeted action to restore

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biodiversity where intensive agriculture has led to its loss (CBD, 2012). The maintenance of biodiversity enhances the provision of other ES, particularly those mediated by the soil, e.g. the storage, internal cycling and processing of nutrients (Haygarth and Ritz, 2009) and carbon (Goldstein et al., 2012). However, intensive agricultural practices, including the use of fertilisers, pesticides and tillage are incompatible with high biodiversity (Pilgrim et al., 2010).

Intensive agricultural management results in changes to soil properties including; decreased total soil nitrogen (N), increased N availability, (Knops and Tilman, 2000), decreased soil organic carbon (SOC; McLauchlan, 2006), and increased total and available phosphorus (P) concentration (Gough and Marrs, 1990; McLauchlan, 2006). The most diverse grasslands with plant species of the highest conservation value tend to occur on soils with low nutrient status, as large concentrations of nutrients favours dominance by a small number of species capable of rapid resource utilisation (Critchley et al., 2002; Janssens et al., 1998). Thus, substantial concentrations of legacy soil N and P can limit the biodiversity value of created or restored grasslands (Walker et al., 2004). Legacy soil N and P can also have significant implications for water quality since increased concentrations in water bodies can result in eutrophication (Sondergaard and Jeppesen, 2007; Dungait et al., 2012). Nutrients leached in forms that are readily available for biotic uptake, such as NO_3^- (nitrate), may have a particularly large, immediate effect on the aquatic system.

Legacy effects of past management on soil properties can still be observed after many decades (Kopecký and Vojta, 2009) and in some cases thousands of years (Dupouey et al., 2002) following the cessation of intensive agriculture. Yet there are very few published reports of the co-dynamics of the major macronutrient (N and P) and C cycles in soils following the cessation of agricultural management (Landgraf et al., 2003; Eschen et al., 2006; Du et al., 2007; Fagan et al., 2008; Table S1). The aim of this study was to establish the extent of the legacy effect of former intensive arable management on ES provision including, SOC and macronutrient cycling and biodiversity in recently created (<10 years) species-rich grasslands (SRG). We focussed in particular on the direct measurement of botanical biodiversity provision, and soil chemistry, including SOC, N and P, which are key factors regulating both biodiversity and potential nutrient loss to water bodies, key targets of SRG creation. We tested the hypotheses that:

1. Soil chemical properties (SOC, N and P) will not change within the first 10 years following cessation of intensive management.
2. Legacy macronutrients in soil will prevent the establishment of prescribed species-rich seed mixes.

2. Materials and methods

2.1. Field Sites

Paired field plots (11 m × 11 m) of intensively managed and arable (IM) or extensively managed and sown with species-rich grassland seed mix (SRG) were established in 2010 in fields on 4 farms in SE Scotland. SRG seed mixes (Table 1) had been sown 3, 5, 8 and 9 years previously in a portion of an IM field at each farm. Plot pairs were matched for soil type (silty loam, brown earth, Lauder series; Soil Survey of Scotland, 1981) using soil particle size analysis, slope and aspect. All of the IM plots continued to receive fertiliser throughout the study, in contrast to the SRG plots that had received no fertiliser or biocides since conversion (full details in Horrocks et al., 2015). Hereafter, each site is identified by the letter S followed by a number, which refers to the age in years since establishment of the SRG. Before conversion to SRG, sites S3, S8 and S9 had been under arable rotation for at least 20 years, and site S5 had been under intensive arable management until 2 years prior to establishment of the SRG when it was converted to intensive grassland management.

2.2. Soil properties

2.2.1. Sampling and preparation

Sites S3, S8 and S9 were sampled in spring (late March) and summer (early July) in 2010 and 2011. The site at S5 was not sampled in 2011, having withdrawn from the agri-environment scheme at the end of 2010. Soil cores (5 cm diameter × 10 cm length, $n = 5$) were sampled in a cross diagonal pattern from each plot (Been and Schomaker, 2013). Surface soil cores (0–10 cm

Table 1
Mean ($n = 5$) soil organic carbon (SOC), total nitrogen (N) and total phosphorus (P) content in samples collected from paired intensively managed (IM) and 'species-rich' grassland (SRG) plots at 4 sites in the Scottish Borders. Values in brackets show 1 standard deviation, where a t-test indicated that a value was significantly greater ($p < 0.05$) than at the paired plot that figure is in bold.

Site	Season	Depth (cm)	Total SOC (tonne ha^{-1})				Total N (tonne ha^{-1})				Total P (tonne ha^{-1})			
			2010		2011		2010		2011		2010		2011	
			IM	SRG	IM	SRG	IM	SRG	IM	SRG	IM	SRG	IM	SRG
S3	Spring	0–10	14.4 (2.0)	16.2 (0.9)	20.1 (14.9)	**24.2 (9.3)**	1.40 (0.20)	1.63 (0.07)	1.85 (1.44)	1.70 (1.20)	0.12 (0.11)	0.19 (0.12)	0.29 (0.05)	0.40 (0.10)
	Spring	30–40	11.7 (1.7)	14.0 (1.1)	17.4 (12.3)	11.1 (2.0)	1.21 (0.19)	1.38 (0.14)	1.26 (1.27)	1.08 (0.19)	0.11 (0.04)	0.12 (0.04)	0.25 (0.02)	0.31 (0.04)
S5	Spring	0–10	24.8 (4.3)	28.3 (4.0)	–	–	2.46 (0.47)	2.58 (1.24)	–	–	0.29 (0.05)	**0.46 (0.14)**	–	–
	Spring	30–40	24.0 (6.1)	24.2 (7.5)	–	–	2.38 (0.56)	2.32 (0.63)	–	–	0.24 (0.06)	0.43 (0.19)	–	–
S8	Spring	0–10	28.2 (5.7)	23.5 (1.9)	24.5 (5.1)	19.7 (4.1)	2.67 (0.49)	2.22 (0.20)	2.31 (0.51)	1.22 (1.02)	0.46 (0.09)	0.35 (0.05)	0.48 (0.12)	0.32 (0.03)
	Spring	30–40	22.4 (2.2)	21.7 (2.4)	33.1 (12.0)	32.1 (11.6)	2.20 (0.18)	2.13 (0.24)	3.06 (1.04)	2.58 (0.65)	**0.40 (0.07)**	0.31 (0.04)	0.34 (0.13)	0.41 (0.06)
S9	Spring	0–10	**38.7 (3.5)**	31.2 (1.1)	29.6 (12.4)	24.1 (11.7)	3.69 (0.32)	2.92 (0.16)	2.72 (1.33)	1.73 (1.28)	0.81 (0.07)	0.60 (0.03)	0.64 (0.16)	0.52 (0.03)
	Spring	30–40	37.9 (2.7)	28.1 (1.6)	25.5 (16.7)	25.2 (9.3)	3.64 (0.26)	2.67 (0.22)	2.33 (1.49)	2.28 (0.83)	0.77 (0.04)	0.54 (0.05)	0.70 (0.05)	0.43 (0.09)

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