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The influence of seed mix and management on the performance and persistence of sown forbs in buffer strips

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Summary

A popular option under agri-environmental schemes throughout Europe has been the introduction of buffer strips adjacent to field boundaries. Buffer strips are usually established using grass-only seed mixes, or through natural regeneration. As a consequence, their function and biodiversity value might be limited due to a low presence of desirable forb species. Given the financial barrier of using forb-rich seed mixes, there is a need to identify species that establish reliably in parallel with management options that encourage their persistence.

In a 5-year study across three different sites we investigated the responses of 32 different forb species sown in two different grass-based seed mixes tailored to soil type. Generally, there was an increase in sown forb cover with time, and this effect was greatest in plots sown with fine-grasses treated with an application of graminicide or an annual cut. We have identified a suite of ten forb species that are likely to establish and persist in buffer strip habitats.

Key words: Field margins, plant traits, wildflower establishment, sowing success

Introduction

In Europe, agri-environmental schemes have an important role in protecting natural resources and promoting biodiversity (Ekroos *et al.*, 2014). A very popular option under such schemes has been the introduction of buffer strips adjacent to field boundaries. It is evident that these vegetated strips can benefit a range of farmland species including bees (Carvell *et al.*, 2007), butterflies (Feber *et al.*, 1996), and birds (Vickery *et al.*, 2009). However, their biodiversity value might be limited as most are left to regenerate naturally or are established using grass-only seed mixes. As a consequence, studies have investigated the inclusion of herbaceous wildflower species (forbs) in seed mixes, or their subsequent introduction into the sward (Blake *et al.*, 2011).

Given the financial barriers of using species-rich wildflower seed mixes (Feltham *et al.*, 2015), there is a need to identify species that not only establish reliably in buffer strips, but also persist for the duration of agri-environment agreements (typically 5 years). The main aim of this paper was to investigate the performance of forb species sown in different seed mixes under the influence of three different sward management treatments. However, a further aim was to investigate the influence of seed mix type and sward management on values of total forb cover in the buffer strips. This will reveal the potential of the different seed mixes and management treatments to deliver floral resources.

Materials and Methods

Experimental design

At three UK sites, non-cropped perennial arable buffer strips were established on clay (ADAS Boxworth, 52:15:10N, 0:01:54W), sand (ADAS Gleadthorpe, 53:13:28N, 1:06:45W) and chalk soils (ADAS High Mowthorpe, 54:06:29N, 00:38:36W). At each site, five replicate blocks each consisting of nine experimental plots measuring 25 m × 5 m were established with three different seed mixes. Individual plots were separated by 5 m buffers. In each of the five blocks, three randomly selected plots were sown with a tussock grass and forb mixture (TG), and three with a fine grass and forb mixture (FG) (see Table 1 for a list of forbs sown). The final three plots were sown with a mix consisting solely of grasses and is not considered in this paper. Boxworth and High Mowthorpe were both sown in autumn 2001, whilst due to inundation, Gleadthorpe was sown in spring 2002. The sowing rates for the TG mix was 35.1 kg ha^{-1}, and 36.2 kg ha^{-1} for the FG mix, which equated to 20% forbs and 80% grasses by weight. During the first year after sowing (2002), all plots were cut in late summer with a tractor-mounted flail cutter to a height of approximately 15 cm; cuttings were left *in situ*.

Following the establishment year, the management treatments of cutting, sward scarification and selective graminicide were applied annually in March/April to individual plots according to seed mix type for a period of 4 years. This created a randomised three by two factorial design within each replicate block. The cutting treatment was applied to reflect the management practice typically adopted by farmers, whilst scarification was used as a tool to reduce above-ground biomass, provide opportunities for plant regeneration, and increase sward access for farmland birds (Westbury *et al.*, 2017). The application of a selective graminicide served to reduce the dominance of susceptible grass species and promote forb abundance (Westbury & Dunnett, 2008).

Scarification was applied using a power harrow to create approximately 60% bare ground by cultivating the top 2.5 cm. The selective graminicide fluazifop-P-butyl (Fusilade Max™, Syngenta Crop Protection Ltd) was used, applied at half the label rate (0.8 L ha^{-1}), in a volume rate of 200 L ha^{-1} with a tractor-mounted sprayer. This is equivalent to 100 g active ingredient ha^{-1}. To improve the efficacy of the sward scarification and graminicide treatments, plots were cut to a height of approximately 30 cm with a flail cutter 2–3 weeks prior to their application. Management of the cropped area adjacent to the buffer strips was based on a 4 year crop rotation, starting with 3 years of winter wheat, followed by either field beans, potatoes, or winter oil seed rape.

Botanical assessments

Botanical assessments were performed in June (2002, 2003, 2004, and 2006) in each plot using a 50 cm × 50 cm quadrat. Ten replicate quadrats were randomly positioned within each plot, leaving a perimeter buffer of approximately one metre within each plot to take account of edge effects. All vascular plant species were identified and assigned a percentage cover value (non-repetitive cover by vertical projection) according to an eight-point scale (1 = < 1%, 2 = 1–5%, 3 = 6–10%, 4 = 11–20%, 5 = 21–40%, 6 = 41–60%, 7 = 61–80%, and 8 = 81–100%). Plant nomenclature follows Stace (2010).

Table 1. *Species composition and sowing rates of forbs according to seed mix type. The Tussock grass & forb mix was sown across all three sites; the Fine grass & forb mix was tailored according to site*

Sown Species	Tussock grass & forb mix (kg ha^{1})	Fine grass & forb mix (kg ha^{1})		
		Boxworth	Gleadthorpe	High Mowthorpe
Achillea millefolium	0.4	0.2	0.2	0.2
Anthyllis vulneraria	-	-	-	0.5
Centaurea nigra	0.8	0.4	0.4	0.2
Centaurea scabiosa	0.6	-	-	0.4
Daucus carota	0.8	0.4	0.5	0.4
Dipsacus fullonum	0.6	-	-	-
Echium vulgare	-	-	0.5	-
Galium mollugo	0.7	-	-	-
Galium verum	-	0.5	0.4	0.7
Geranium pratense	0.6	0.4	-	-
Knautia arvensis	-	0.5	-	0.5
Lathyrus pratensis	0.4	-	-	-
Leontodon hispidus	-	0.4	-	0.4
Leucanthemum vulgare	0.7	0.5	0.4	0.4
Linaria vulgaris	-	-	0.2	-
Lotus corniculatus	-	0.2	0.2	0.4
Malva moschata	-	0.5	0.7	-
Origanum vulgare	-	-	-	0.4
Pimpinella saxifraga	-	-	-	0.4
Plantago lanceolata	-	0.4	0.4	0.4
Plantago media	-	-	0.2	0.4
Primula veris	-	0.4	0.4	0.4
Prunella vulgaris	-	0.4	0.4	0.4
Ranunculus acris	-	1.2	0.5	0.5
Ranunculus bulbosus	-	-	0.5	-
Reseda lutea	-	-	-	0.2
Rhinanthus minor	-	0.4	0.4	0.2
Rumex acetosa	-	0.4	0.4	-
Sanguisorba minor	-	-	-	0.9
Silene dioica	1.1	-	-	-
Silene vulgaris	-	-	0.7	-
Vicia cracca	0.4	0.5	-	-

Data analysis

Differences in the performance of individual forb species between treatments were not statistically analysed, in part because small differences in species with low values of cover will not necessarily be coupled with any biological significance. Instead, species with an average plot cover value of at least 4% were classed as 'good performers', enabling the relative value of sowing a species to be assessed. For the purpose of this paper, cover data of individual species from Year 2 (when the sward treatments were first applied), has been compared with data from Year 5, enabling a comparison of species performance across the study period. Cover values of individual species were converted from the eight-point scale to a percentage cover mid-point (1 = 0.5%, 2 = 2.5%, 3 = 7.5%, 4 = 15%, 5 = 30%, 6 = 50%, 7 = 70%, and 8 = 90%).

For analyses of total cover abundance, seed mix type (TG, and FG), management treatment (cutting, scarification, and graminicide), and year, including the interactions between all these factors were set as fixed effects in a mixed linear model in SAS Studio (Version 3.6, 2016). The variable year was also specified as a repeated measure with an autoregressive covariance structure. Site, and block nested within site, were specified as random effects. Degrees of freedom were calculated using the iterative Satterthwaite's method (Schabenberger & Pierce, 2002). Model simplification was performed by sequentially deleting interactions and then factors which were not significant, unless part of significant interaction term. Prior to analysis, cover values based on those converted from the eight-point scale were log (x+1) transformed.

Results

The performance of individual forb species

The establishment of the 32 sown forbs was variable across sites, and three species, *Echium vulgare*, *Pimpinella saxifraga* and *Reseda lutea* were not recorded in quadrats during the 5-year study. The mean cover of some species was also very low (less than 0.05%) for *Lathyrus pratensis*, *Origanum vulgare*, *Ranunculus bulbosus* and *Reseda lutea* (Table 2.). Based on an average plot value of at least 4% cover being classed as a 'good performance', a number of key species have been identified (Table 2.). There was a tendency for most of the good performers to attain greatest abundance by year 5, but this was also influenced by treatment. For example, by year 5, *Galium mollugo* had an average of 22.1% (± 5.6) cover in plots treated with graminicide and 6.8% (± 1.8) in plots managed with cutting, but only 0.7% in plots that were scarified. In contrast, *Rumex acetosa* responded positively to scarification (7.2% ± 2.7) and graminicide (5.7% ± 2.2), but was of lower abundance in plots managed solely with cutting (3.1% ± 1.5) (Table 2). The performance of *Ranunculus acris* was deemed 'good' in year 5 but only in plots that were treated with graminicide. *Leucanthemum vulgare* performed well in year 2, but values had decreased substantially by year 5; in contrast, *Lotus corniculatus* performed well in year two and became substantially more abundant in association with all treatments by year 5.

Overall performance of the sown forbs

Total sown forb cover in the buffer strip plots was strongly influenced by seed mix type ($F_{1,330}$ = 13.1, P<0.001), sward treatment ($F_{2,330}$ = 12.7, P<0.001), and year ($F_{3,330}$ = 113.0, P<0.001). However, the interactions between year and seed mix type ($F_{3,330}$ = 5.2, P<0.01), and year and sward treatment ($F_{6,330}$ = 2.8, P<0.05), were also significant, making interpretation of the main effects difficult. There was a tendency for forb cover values in both seed mix types to increase substantially after the establishment year. During years 2, 3 and 5, cover values in plots sown with the tussock grass and forb mix remained fairly constant, whilst values in plots sown with the fine grass and forb mix had increased dramatically after year three (Fig. 1).

The significant interaction between sward treatment and year indicates that responses to treatment were not consistent with time (Fig. 2). In the establishment year all plots received the same single treatment of cutting in late summer and as a consequence values of forb cover were similar in year 1 across all treatment plots. Differences between treatments became apparent from year 2, with values of total sown forb cover being greater in plots treated with graminicide, whilst scarification was associated with lower values relative to cutting.

Table 2. *A comparison of average percentage cover values (± SE) for the sown forb species between year 2 (the first year of sward management treatments being applied) and year 5, according to sward management treatment. Cut = Cutting; Scar = Scarification; Gram = Graminicide. Average values are based solely on values from plots in which the species was sown. Species with values 4% or greater are given in bold*

Species	Year 2			Year 5		
	Cut	Scar	Gram	Cut	Scar	Gram
Achillea millefolium	2.4 (± 0.7)	2.1 (± 0.7)	2.5 (± 0.6)	**4.6 (± 1.6)**	1.8 (± 0.6)	**5.4 (± 1.0)**
Anthyllis vulneraria	1.8 (± 0.9)	1.0 (± 0.9)	3.5 (± 1.1)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Centaurea nigra	0.9 (± 0.2)	1.0 (± 0.3)	1.2 (± 0.2)	**4.0 (± 1.2)**	2.0 (± 0.5)	**5.1 (± 1.4)**
Centaurea scabiosa	0.1 (± 0.1)	0.1 (± 0.1)	0.1 (± 0.1)	0.0 (± 0.0)	0.3 (± 0.3)	0.1 (± 0.1)
Daucus carota	0.8 (± 0.3)	0.8 (± 0.2)	1.1 (± 0.3)	1.9 (± 1.0)	2.6 (± 0.7)	1.8 (± 0.5)
Dipsacus fullonum	3.1 (± 0.8)	3.3 (± 0.9)	**5.0 (± 1.7)**	2.8 (± 1.0)	**5.4 (± 2.0)**	**5.6 (± 2.7)**
Echium vulgare	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Galium mollugo	1.9 (± 0.5)	1.1 (± 0.3)	1.7 (± 0.4)	**6.8 (± 1.8)**	0.7 (± 0.4)	**22.1 (± 5.6)**
Galium verum	0.7 (± 0.3)	0.4 (± 0.2)	0.6 (± 0.2)	2.3 (± 1.3)	1.6 (± 0.7)	3.8 (± 1.4)
Geranium pratense	0.5 (± 0.1)	1.1 (± 0.6)	0.6 (± 0.1)	2.0 (± 0.6)	3.4 (± 0.9)	**4.1 (± 1.3)**
Knautia arvensis	0.1 (± 0.1)	0.0 (± 0.0)	0.0 (± 0.0)	0.4 (± 0.3)	0.6 (± 0.6)	0.6 (± 0.4)
Lathyrus pratensis	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Leontodon hispidus	0.2 (± 0.1)	0.1 (± 0.1)	0.0 (± 0.0)	0.4 (± 0.3)	0.3 (± 0.2)	0.4 (± 0.2)
Leucanthemum vulgare	**10.5 (± 2.5)**	**6.2 (± 1.1)**	**16.2 (± 4.0)**	3.7 (± 1.6)	2.3 (± 0.7)	2.7 (± 0.8)
Linaria vulgaris	0.0 (± 0.0)	0.1 (± 0.0)	0.3 (± 0.3)	0.1 (± 0.1)	0.5 (± 0.5)	0.2 (± 0.1)
Lotus corniculatus	**6.7 (± 3.0)**	**5.3 (± 2.1)**	**7.4 (± 2.7)**	**23.1 (± 5.9)**	**9.1 (± 3.5)**	**20.9 (± 6.5)**
Malva moschata	0.7 (± 0.3)	1.0 (± 0.5)	0.5 (± 0.3)	2.0 (± 1.4)	1.7 (± 1.1)	1.7 (± 0.8)
Origanum vulgare	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Pimpinella saxifraga	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Plantago lanceolata	2.8 (± 1.1)	3.0 (± 0.7)	3.7 (± 1.2)	**6.5 (± 1.8)**	**17.5 (± 3.0)**	**9.5 (± 1.7)**
Plantago media	0.2 (± 0.1)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.1 (± 0.1)	0.0 (± 0.0)
Primula veris	0.1 (± 0.0)	0.0 (± 0.0)	0.1 (± 0.1)	0.4 (± 0.1)	0.1 (± 0.1)	0.4 (± 0.2)
Prunella vulgaris	0.6 (± 0.2)	0.6 (± 0.3)	0.3 (± 0.2)	0.6 (± 0.2)	0.8 (± 0.4)	0.5 (± 0.2)
Ranunculus acris	2.0 (± 0.5)	1.4 (± 0.3)	1.5 (± 0.3)	3.9 (± 1.1)	1.5 (± 0.6)	**5.4 (± 1.7)**
Ranunculus bulbosus	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Reseda lutea	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
Rhinanthus minor	1.0 (± 0.5)	0.4 (± 0.3)	1.5 (± 0.5)	1.4 (± 0.5)	0.0 (± 0.0)	1.5 (± 0.8)
Rumex acetosa	2.4 (± 1.1)	2.3 (± 0.8)	2.2 (± 0.8)	3.1 (± 1.5)	**7.2 (± 2.7)**	**5.7 (± 2.2)**
Sanguisorba minor	0.1 (± 0.0)	0.2 (± 0.1)	0.2 (± 0.1)	0.1 (± 0.0)	0.0 (± 0.0)	0.1 (± 0.0)
Silene dioica	0.8 (± 0.2)	0.6 (± 0.2)	1.5 (± 0.4)	0.1 (± 0.1)	0.1 (± 0.1)	0.8 (± 0.3)
Silene vulgaris	2.3 (± 0.7)	2.0 (± 0.5)	3.4 (± 1.6)	**4.2 (± 2.0)**	**6.1 (± 1.9)**	**4.2 (± 1.9)**
Vicia cracca	1.2 (± 0.6)	1.2 (± 0.5)	1.3(± 0.6)	2.0 (± 0.7)	1.0 (± 0.6)	**4.0 (± 1.6)**

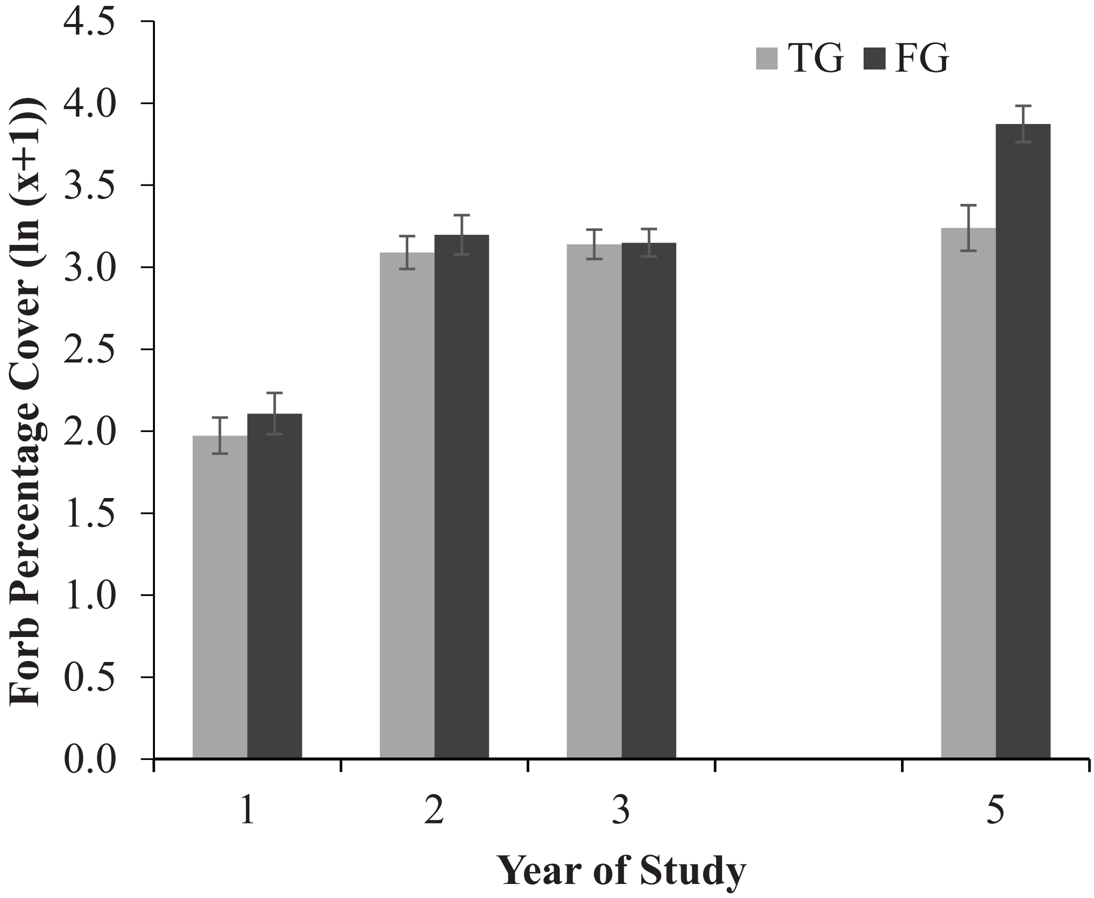

Fig. 1. Mean percentage values of total forb cover (ln (x+1)) (±SE) according to seed mix type (TG = Tussock grass and forb, FG = Fine grass and forb), and year of study.

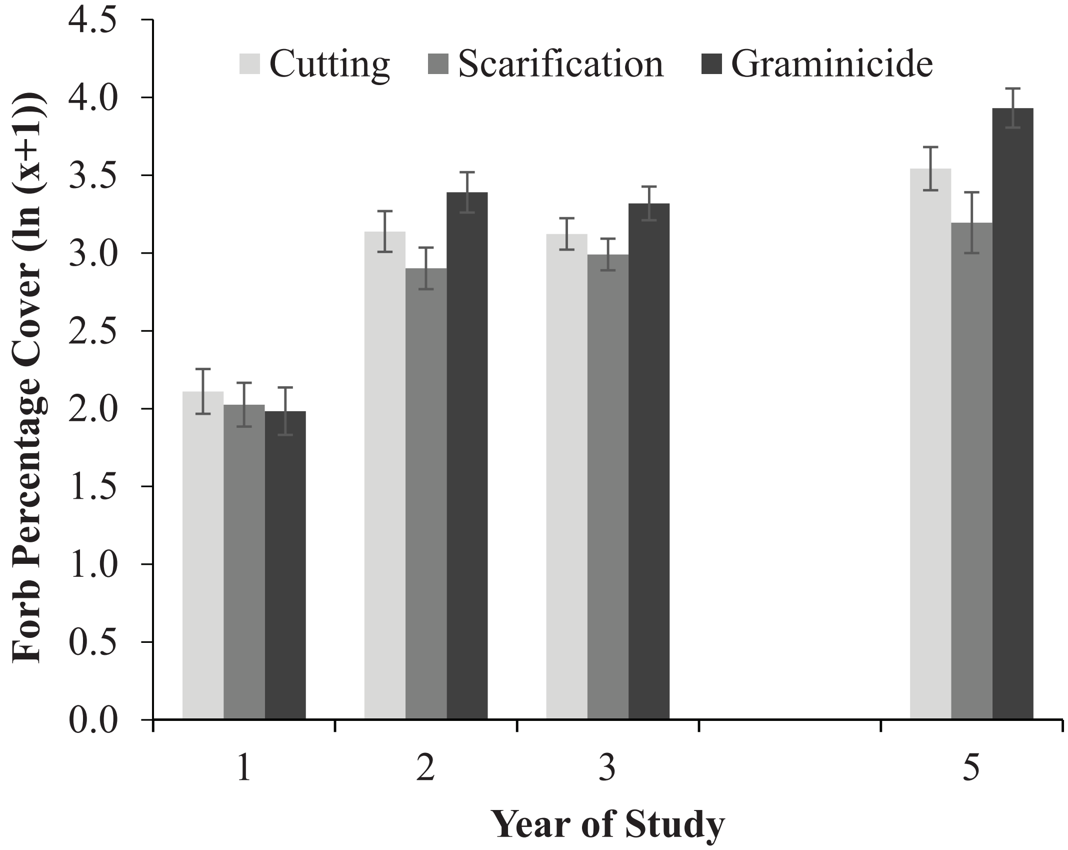

Fig. 2. Mean percentage values of total forb cover (ln (x + 1)) (±SE) according to sward treatment (cutting, scarification, and selective graminicide), and year of study.

Responses to the three management treatments remained fairly constant in years 2, 3, and 5, although by year 5 the differences between scarification and the application of graminicide were greater (Fig. 2). The interaction between seed mix type and sward treatment was not significant.

Discussion

Overall, 12 forb species have been identified that performed well either during the second year of study, and/or by the end of the 5-year study, but only 10 of these species were sown across all three sites (soil types). The performance of *Rumex acetosa* and *Silene vulgaris* was classed as 'good', but *R. acetosa* was only sown at Boxworth (clay) and Gleadthorpe (sand), whilst *S. vulgaris* was sown only at Gleadthorpe. Generalisations about these two species across soil types therefore cannot be made. Based on the findings of this 5-year study, it is recommended that basic buffer strip seed mixes should consist of the 10 key species shown in Table 3. The sowing rate of 5.2 kg ha^{-1} is based on the average rate that each species was sown across the study. Sowing rates of certain species could be increased if greater cover values were desired e.g. *Geranium pratense* or *Vicia cracca*. This forb mix should be sown in conjunction with a selection of grass species that were also sown in the study, including *Cynosurus cristatus*, *Dactylis glomerata, Festuca pratensis*, *Festuca rubra,* and *Phleum pratense*, at a total rate of 20 kg ha^{-1}.

It is important to note that the performance of some species was only deemed 'good' in conjunction with a particular sward treatment. For example, a good performance of *G. pratense*, *R. acris*, and *V. cracca* in year five was restricted to plots treated with graminicide, whilst *Plantago lanceolata* responded positively to all sward treatments. It is evident that the application of graminicide generally enhanced forb performance (11 of the 12 species, compared to six with cutting), an outcome which is fully supported by other studies (Westbury & Dunnett, 2008; Blake *et al.*, 2011). However, under English agri-environmental scheme rules, current buffer strip management is restricted to cutting, which might limit the benefits and value of including some forb species in buffer strips (Westbury *et al.*, 2017).

Table 3. *Recommended species composition and sowing rates of forbs for a general purpose buffer strip seed mix*

Species	Sowing Rate (Seeds m^{-2})	Sowing Rate (kg ha^{-1})
Achillea millefolium	180	0.30
Centaurea nigra	26	0.57
Dipsacus fullonum	18	0.60
Galium mollugo	105	0.70
Geranium pratense	6	0.55
Leucanthemum vulgare	113	0.57
Lotus corniculatus	13	0.27
Plantago lanceolata	10	0.40
Ranunculus acris	29	0.73
Vicia cracca	3	0.50
	Total Sowing Rate	5.2 kg ha^{-1}

A key issue in comparing the performance of species in seed mixes is whether individual species are given an equal opportunity to perform irrespective of their plant traits, an aspect not considered previously e.g. Pywell *et al.* (2003). Comparisons between seed mixes is confounded by the composition of mixes influencing the competitive interactions between species. For example, *P. lanceolata* is not a suitable host for *Rhinanthus minor* and so the performance of *R. minor* might be expected to be better in plots not sown with *P. lanceolata* (Cameron *et al.*, 2006). The time of sowing will also differentially affect species performance. For example, species that require a period of winter chilling such as *R. minor* (Westbury, 2004) and *Primula veris* (Brys & Jacquemyn, 2009) can be disadvantaged if sown in the spring. The Gleadthorpe site was sown in the spring and performance of both *Primula veris* and *R. minor* was markedly lower compared to the other sites. Establishment success can also be increased dramatically if some species are sown immediately after seed harvest, for example *Knautia arvensis* (D. Westbury, *personal observation*), and this species is frequently reported as performing poorly in commercial off the shelf seed mixes (Pywell *et al.*, 2003).

The sowing rates of species is also likely to be important, which must also take into account differences in seed viability and germination rates between species. In the current study, sowing rates were not consistent across species, with higher sowing rates typically being associated with species for which seed costs are lower. For example, *Leucanthemum vulgare* was sown at between 100 and 140 seeds m^{-2}, whilst *Lathyrus pratensis* was sown at 2.4 seeds m^2. The cost of purchasing 1,000 *L. vulgare* seeds, is currently £0.06 (at the 100 g rate), compared to £7.67 for *L. pratensis*. Seed cost is based on a number of factors, but key to pricing is the relative ease of harvesting seed and the quantities obtained. However, some species sown at relatively high rates did not perform well in the buffer strips. These included *Silene dioica*, which was sown at a rate of 110 seeds m^{-2}, *Galium verum* (76–133 seeds m^{-2}), and *Daucus carota* (40–80 seeds m^{-2}). In contrast, *G. pratense* and *V. cracca* had good performance following very low sowing rates. The relationship between sowing rate and performance is therefore not clear.

To ensure a more even establishment of forb species in buffer strips, two different approaches should be considered, i) sow species at rates that reflect their establishment potential (as in Table 3), or ii) sequentially sow poor performing species once sward productivity and the dominance of unsown ruderal species has declined, using a combination of sward scarification and selective graminicide (Blake *et al.*, 2011).

Based on the sowing rates used in this study, we have identified a suite of species that have the potential to contribute substantially to the composition of buffer strips over a 5-year period. However, we have not investigated whether sowing some of the species identified as poor performers at higher sowing densities would have resulted in different project outcomes.

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References

Blake R J, Woodcock B A, Westbury D B, Sutton P, Potts S G. 2011. New tools to boost butterfly habitat quality in existing grass buffer strips. *Journal of Insect Conservation* **15**:221–232.

Brys R, Jacquemyn H. 2009. Biological Flora of the British Isles*: Primula veris* L. *Journal of Ecology* **97**:581–600.

Cameron D D, Coats A M, Seel W E. 2006. Differential resistance among host and non-host species underlies the variable success of the hemi-parasitic plant *Rhinanthus minor*. *Annals of Botany* **98**:1289–1299.

Carvell C, Meek W R, Pywell R F, Goulson D, Nowakowski M. 2007. Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. *Journal of Applied Ecology* **44**:29–40.

Ekroos J, Olsson O, Rundlof M, Watzold F, Smith H G. 2014. Optimizing agri-environment schemes for biodiversity, ecosystem services or both? *Biological Conservation* **172**:65–71.

Feber R E, Smith H, Macdonald D W. 1996. The effects on butterfly abundance of the management of uncropped edges of arable fields. *Journal of Applied Ecology* **33**:1191–1205.

Feltham H, Park K, Minderman J, Goulson D. 2015. Experimental evidence that wildflower strips increase pollinator visits to crops. *Ecology and Evolution* **5**:3523–3530.

Pywell R F, Bullock J M, Roy D B, Warman L, Walker K J, Rothery P. 2003. Plant traits as predictors of performance in ecological restoration. *Journal of Applied Ecology* **40**:65–77.

Schabenberger O, Pierce F J. 2002. *Contemporary statistical models for the plant and soil sciences.* London, UK: CRC Press.

Stace C. 2010. *New flora of the British Isles,* Cambridge, UK: Cambridge University Press.

Vickery J A, Feber R E, Fuller R J. 2009. Arable field margins managed for biodiversity conservation: A review of food resource provision for farmland birds. *Agriculture, Ecosystems & Environment* **133**:1–13.

Westbury D B. 2004. Biological Flora of the British Isles. *Rhinanthus minor* L. *Journal of Ecology* **92**:906–927.

Westbury D B, Dunnett N P. 2008. The promotion of grassland forb abundance: A chemical or biological solution? *Basic and Applied Ecology* **9**:653–662.

Westbury D B, Woodcock B A, Harris S J, Brown V K, Potts S G. 2017. Buffer strip management to deliver plant and invertebrate resources for farmland birds in agricultural landscapes. *Agriculture, Ecosystems & Environment* **240**:215–223.