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Sustainable Arable Farming For an Improved Environment (SAFFIE): managing winter wheat sward structure for Skylarks *Alauda arvensis*

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Research has shown a close correlation between the decline of the UK Skylark *Alauda arvensis* population and the replacement of spring-sown cereals with winter-sown varieties, in which advanced sward development prevents successful multiple nesting attempts and reduces access for foraging. Widescale reversal of sowing times is unlikely for commercial reasons, so research has recently focused on ways of manipulating the sward structure of winter wheat to prolong access to nest-sites and food. An RSPB pilot study investigated leaving small 'undrilled patches' in otherwise conventionally managed winter wheat crops. This option was later incorporated into a fully replicated experimental design, as part of the Sustainable Arable Farming For an Improved Environment (SAFFIE) project. This large consortium-led project aims to test solutions for improving biodiversity within winter-cereal-dominated rotations. The experiment described here ran over 2002–3, with three field-scale 'treatments' on 15 sites in the first year. The treatments compare (1) conventional winter wheat, (2) winter wheat sown in double-normal width (25 cm) wide-spaced rows (WSR) and (3) winter wheat with two 4-m by 4-m undrilled patches per hectare (UP). Results from the 2002 breeding season showed that undrilled patch treatments supported more breeding Skylarks for longer, most likely by aiding accessibility of food. WSR rows were little used by Skylarks and did not improve the abundance of favoured seed and invertebrate food items over conventional crops. Nesting performance and foraging patterns are discussed with reference to invertebrate food abundance and its accessibility, as determined by sward structure.

In 2002, winter wheat crops were grown on over 2 million hectares of British farmland. In contrast, the area sown with all types of spring cereals was 600 000 ha. This figure represented an 80% decrease from the 1970 spring-sown total, compared with a decrease of just 13% in the total area of cereals grown. In some regions where soil conditions mean that spring cultivation is regarded as high risk, winter wheat may account for nearly 90% of all cereal crops (< 3.5% of which are spring sown) (Anon. 2002).

The severe decline of 52% in the UK's Skylark *Alauda arvensis* population between 1970 and 1999 (Gregory *et al*. 2003) has resulted in its listing as a UK Biodiversity Action Plan Priority Species. Skylark is also one of the 19 species of farmland birds that contribute to the UK Government's Quality of Life breeding bird indictor. The government also has a Public Service Agreement to reverse the long-term decline in the number of farmland birds by 2020 (Gregory *et al*. 2004). Donald and Vickery (2000) identified a striking correlation between the replacement of spring-sown cereals with winter-sown varieties and the decline in Skylark abundance. The shift in sowing times is likely to have impacted on the Skylarks via a number of different mechanisms. During winter, the loss of weedy stubbles (a key source of weed seed, spilt grain and invertebrate food) resulting from winter sowing of cereals is likely to have been detrimental (Robinson 2001). There is also

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mounting evidence that the structure of winter wheat results in a relatively poor nesting and foraging habitat for Skylarks during the breeding season. Donald (2004) suggests that Skylarks prefer vegetation less than 50 cm in height for nesting and less than 25 cm in height for foraging. Thus, winter cereals, for which canopy heights usually exceed 25 cm during the first week in May and 50 cm by the end of May (Donald *et al*. 2001), represent a suboptimal habitat for most of the breeding period, which historically extended from the start of April until well into August. Although accurate empirical data are lacking on the exact number of breeding attempts possible in winter wheat, estimates suggest 1–2 attempts in winter wheat compared with 3–4 in spring cereals. Donald (2004) identifies a curtailment of the breeding season in arable crops as one of the main reasons for the decline in UK Skylark abundance. Even when Skylarks are able to make later nesting attempts in winter cereals by utilizing barer areas, such as tramlines created by farm machinery, it has been demonstrated that nest survival is poor due, principally, to losses to opportunistic predators using these features to move through the crop (Donald *et al*. 2002).

Having identified the extent of the problem and the likely mechanisms behind the decline (Donald & Vickery 2001), research effort switched to seeking practical solutions designed to reverse the trend. Options promoting overwinter stubble and spring cropping already existed in various agri-environment schemes, including some Environmentally Sensitive Areas, the Arable Stewardship Pilot Scheme, the subsequent Countryside Stewardship Arable Options and now the pilot Entry Level Scheme in England. However, in conditions where spring cereals were regarded as high risk (or difficult to accommodate within the work schedule), there was a dearth of options for in-crop management of winter cereals during the breeding season. Given that winter cereals make up a large area of the UK's farmland, measures benefiting breeding Skylarks in this habitat clearly had potential to help reverse the decline and were identified as a research priority. While seeking to deliver biodiversity and quality-of-life targets, both the UK Government and environmental non-governmental organizations (NGOs) acknowledged that there were strong economic pressures on UK cereal growers and that these potentially conflicting objectives were unlikely to be reconciled unless solutions were easy to implement at a minimal (and preferably remunerable) cost to the producer.

METHODS

One such low-cost solution was to manipulate the sward structure of winter wheat, with the objective of enhancing access for nesting and foraging Skylarks. In 2001, the RSPB piloted undrilled patches (UP) – also known as 'Skylark Scrapes' – on their own farm in Cambridgeshire. Small patches, approximately 4 m by 4 m in size, depending on the type of drill in use, were created at a density of two per hectare by briefly turning off the seed drill during sowing. UP were positioned away from tramlines to minimize access to mammalian predators moving through the crop. The resultant patches were then managed in the same way as the surrounding conventional wheat crop to minimize disruption to farming operations and to ensure that herbicides controlled potential weed infestations in the patches. Although herbicide use generally restricted pernicious weeds (such as Black-grass *Alopecurus myosuroides* and Cleavers *Galium aparine*), the lack of crop competition, together with a trickle-off effect from shutting off the seed drills, resulted in most patches developing a low, sparse vegetation cover of grass, broad-leaved arable weeds and crop. However, vegetation development was variable both between and within sites.

Results of this trial were so encouraging that it was decided to trial UP more widely in 2002. The Sustainable Arable LINK SAFFIE project provided the ideal opportunity. This collaborative project, involving stakeholders from NGOs, industry and government, seeks to develop a balance of farming and conservation practices compatible with profitable production and enhanced biodiversity. The initial module, Experiment 1.1, ran in 2002 and 2003 and manipulated the vegetation structure of winter wheat to create a more open crop beneficial to crop-dwelling invertebrates, arable weeds and breeding Skylarks.

Study sites and treatments

In 2002, experimental manipulations of crop architecture took place at 15 sites (ten sites were officially part of SAFFIE Experiment 1.1 but the RSPB also collected Skylark data from an additional five sites, as part of their contribution to SAFFIE) situated in north and east Yorkshire, Norfolk, Suffolk, Cambridgeshire, Bedfordshire, Oxfordshire and Wiltshire. On each site, three treatments were compared: (1) conventional winter wheat (Control), (2) winter wheat sown in wide-spaced rows (WSR) at double-normal widths (*c.* 25 cm) and (3) UP treatments, created and managed in the same way as in the RSPB pilot project. Each treatment was a minimum of 5 ha in size and could be either a whole field unit or a subdivided field.

Vegetation data

To provide data on nesting and foraging substrates within the crop, vegetation height and density (using estimates of the proportion of a graduated board obscured at different heights when viewed from 1 m distance) and the percentage cover of all plant species (including crop and volunteer crops) and bare ground were assessed. Weed species were grouped into broad-leaved species (including volunteer oilseed rape) and grasses for analysis. Twenty-four 0.25-m^2 permanent quadrats were placed in each treatment in eight randomly placed groups of three quadrats. An additional 24 quadrats were placed within eight of the patches per UP treatment. Quadrats were surveyed in May and July

Invertebrate data

Three methods were employed to sample all invertebrate groups present in Skylark diet. These were Dvac suction sampling (May, June and July in the vegetation quadrats), sweep netting using D-frame kite nets (May and June in Control and WSR only, with two samples of 20 sweeps per treatment) and pitfall traps (June in the vegetation quadrats). In order to target areas used by foraging Skylarks, sampling was carried out in mid-field crop (minimum of 30 m from the nearest field boundary) and within the undrilled patches. To provide data on diet, Skylark nestling faecal samples were collected from 43 nests (Control 10, UP 27, WSR 7) from nine sites. Collection and storage of the samples followed the methods of Brickle and Harper (2000). Samples were analysed by the Game Conservancy Trust (GCT) using the methods of Moreby (1988).

Skylark data

Between the start of April and mid August, fieldworkers collected data on the numbers of territorial males in 5-ha plots, the numbers of nests located in the treatments (located by visual observations including the carrying of nest material or food and behaviour indicating the presence of incubating females), nest productivity (nest visits to monitor contents and success), nestling body condition (derived from measurements of body mass and tarsus length) and foraging locations (from observations of parental provisioning of nestlings). Full details are given in Morris *et al.* (2003).

Data analysis

Log transformed data on vegetation cover and structure were analysed in GenStat using ANOVA, with sites as blocks and treatment as a factor. Vegetation data from the two sampling periods (May and July) were analysed separately. Structural data (percentage of the graduated board obscured) were analysed by comparing data collected from Control treatments, WSR treatments and from within the actual undrilled patches (PUP). Comparisons of vegetation cover were made between the three treatments, using a weighted mean for the UP treatment (WUP) that combined data from both the crop and the undrilled patches, relative to their respective areas. Comparisons of vegetation cover were also made between the actual undrilled patches (PUP) and the crop (CUP) within UP treatments.

Invertebrate data from the three sampling periods (May, June, July) were analysed by repeated measures ANOVA, when sufficient sample sizes and equality of variance between all groups permitted. Where these assumptions were not fulfilled, the data were analysed separately, using general ANOVA. For pitfall and Dvac samples, comparisons were between all three treatments (Control, WSR, UP). For sweep net samples, comparison was between Control and WSR only, as no data were collected from UP. All invertebrate data from UP treatments were analysed from the treatment as a whole (i.e. combined PUP and CUP). Invertebrate remains from faecal samples were analysed by compositional analysis, using log ratio analysis and the Restricted Maximum Likelihood method (REML), based on the methods of Brickle and Harper (2000).

For the Skylark data, comparisons were between all three treatments (Control, WSR, UP). Nest productivity figures were calculated using data on daily nest survival rates, numbers of eggs laid, numbers of nestlings hatched and numbers of nestlings leaving the nest, as in Donald *et al.* (2002). In the analyses of Skylark territories, nests, nestling body condition and parental foraging patterns, General Linear Mixed Modelling (GLMM) procedures in GenStat, specifying 'site' as a random effect to account for spatial variation, were used to identify those predictors explaining significant variation in the response variables (Welham 1993, Milsom *et al.* 2000). In the nest analysis, treatment area was forced into the model to control for differences in treatment area. All analyses were conducted using a step-up procedure (in which each variable was added and then deleted from the model in turn, with the most statistically significant variable re-fitted to the model after each iteration) to establish the minimum adequate model (MAM). Any overdispersion in the data was automatically corrected by GenStat procedures. Variations in the numbers of territories and nests were modelled with Poisson errors and log-link functions. Nest failure rates (using field means to control for non-independence of nests in the same field, with number of nest failures per field as the response variable and total exposure days of all nests as the binomial denominator) and foraging patterns (with number of forages within nest field as the response and total number of forages – within and outside of the nest field – from the nest as the binomial denominator) were modelled with binomial errors and a logit link. Nestling condition was modelled using normal errors and identity link, following the methods of Bradbury *et al.* (2003).

RESULTS

Vegetation

Back-transformed means of significant pairwise comparisons for percentage cover and structural analyses are given in Table 1. WSR had significantly greater bare ground than WUP in May and July. All other comparisons between treatments were non-significant. In both months, PUP had significantly less crop cover but more broad-leaved and grass weeds than CUP.

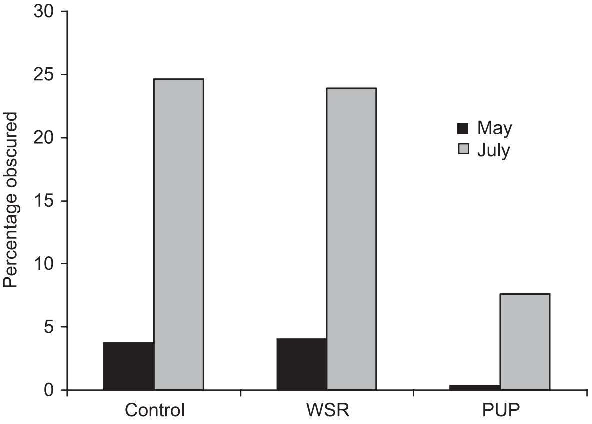

Figure 1. Vegetation structure – percentage of graduated board obscured. Data are shown as back-transformed treatment means.

Analysis of structure data for each treatment at each height indicated significant differences ($P < 0.001$) for height, treatment and height*treatment for both dates. Pairwise comparisons show that PUP had a significantly more open structure than the Control and WSR. Overall treatment means are presented in Figure 1.

Invertebrates

For sweep-net samples that collect canopy-active invertebrates, there were no significant differences

Table 1. Back-transformed means and significance of pairwise comparisons of percentage cover in May and July between (i) treatments (Control, WUP and WSR) and (ii) crop (CUP) and patches (PUP) in the UP treatments.

	May				July				
Variate	Treatments		Crop vs. patches		Control	WUP	WSR	CUP	PUP
B-L species	ns – all pairwise tests		CUP 0.75 $F = 15.3$, $df = 1$, $P = 0.004$	PUP 1.75	ns – all pairwise tests			CUP 1.15 $F = 24.7$, $df = 1$, $P < 0.001$	PUP 12.05
Grasses	ns – all pairwise tests		CUP 0.90 $F = 12.0$, $df = 1$, $P = 0.007$	PUP 2.39	ns – all pairwise tests			CUP 2.46 $F = 54.4$, $df = 1$, $P < 0.001$	PUP 10.78
Crop	ns – all pairwise tests		CUP 34.24 $F = 70.5$, $df = 1$, $P < 0.001$	PUP 2.11	ns – all pairwise tests			CUP 71.02 $F = 70.8$, $df = 1$, $P < 0.001$	PUP 3.17
Bare ground	WUP 84.70 $F = 5.06$, $df = 2$, $P = 0.024$ other pairwise tests ns	WSR 85.81	ns			WUP 75.96 $F = 3.91$, $df = 2$; $P = 0.039$ other pairwise tests ns	WSR 80.92	ns	

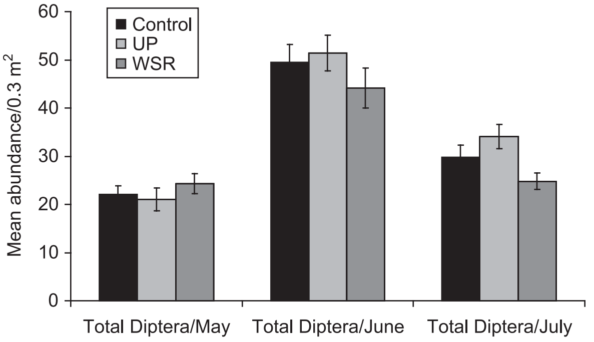

Figure 2. Total number of Diptera between treatments and sampling dates.

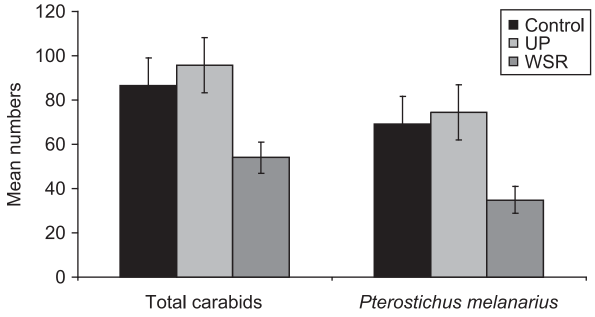

Figure 3. Significant differences between treatments in Coleopteran numbers from pitfall traps in June.

between Control and WSR for any of the groups investigated. The total numbers of Diptera in Dvac samples were significantly influenced both by sampling date ($F = 42$, $df = 2$, $P < 0.001$), with totals peaking in June, and by treatment ($F = 4.3$, $df = 2$, $P = 0.015$), where WSR initially supported a higher number of flies in May but by June they supported fewer individuals than both Control and UP (Fig. 2). The total numbers of Coleoptera in June show that there were significantly more individuals in WSR than in Control or UP ($F = 3.2$, $df = 2$, $P = 0.044$), but this was not the case in May or July.

The pitfall-trap samples showed that the total numbers of carabids and some individual species, in particular *Pterostichus melanarius*, were significantly less abundant in WSR than in the other treatments (Fig. 3). The species richness of the carabid catch and numbers of a few other individual species was also greater on UP than elsewhere but their mean abundance was generally low (fewer than ten individuals per treatment). There were no significant differences between treatments in species composition or the composition of nestling faecal samples, with Coleoptera (42%) and Diptera (30%) comprising most of the nestling diet.

Skylarks

Ninety-nine Skylark nests were located on the treatments (Control $n = 33$, 0.18 nests/ha; WSR $n = 14$, 0.16 nests/ha; UP $n = 52$, 0.31 nests/ha – although only four of these were actually situated within the patches). Results from multivariate models are given in Table 2. Numbers of both Skylark territories and

Table 2. Significance values and direction of the relationships from GLMMs of Skylark: (i) territory, (ii) nest, (iii) nestling body condition and (iv) foraging. The two-level factor 'Period' represents data from April and June in the case of the territory analysis, and 'Early' and 'Late' nesting attempts for all other datasets. This division is based on the mean first egg date of 21 May; with 'Early' nests defined as those with first egg date below the lower 95% confidence interval (< 18 May) and 'Late' nests defined as those with first egg dates above the upper 95% confidence interval (> 24 May). Eight nests with first egg dates within the period 18–24 May are not included, as they could not with certainty be assigned to either period. For WSR, sample sizes were generally small (especially for the foraging analysis) and results should be treated with caution.

	Model			
Term	Territory – data from 43 5-ha plots	Nest – data from 86 nests	Nestling condition – data from 48 broods	Foraging – data from 569 foraging flights
Treatment	Wald 17.37, *df* 2, $P < 0.001$ UP > Control > WSR	Wald 6.27, *df* 2, $P = 0.044$ UP > Control > WSR	ns	Wald 18.24, *df* 2, $P < 0.001$ UP > Control > WSR
Period	Wald 8.14, *df* 1, $P = 0.004$ April > June	Wald 6.78, *df* 1, $P = 0.009$ Early > Late	ns	ns
Period* Treatment	ns	ns	Wald 4.02, *df* 2, $P = 0.029$ Control/Early > Control/Late UP/Early < UP/Late WSR/Early < UP/Late	Wald 14.85, *df* 2, $P < 0.001$ Control/Early > Control/Late UP/Early = UP/Late WSR/Early < UP/Late
Brood size			ns	ns
Tarsus			Wald 180.18, *df* 1, $P < 0.001$	

Table 3. Productivity per nesting attempt. Overall nest survival rate calculated by raising daily survival rate to power 22 – the average duration (1st egg to nestlings leaving nest), in days, of a successful Skylark breeding attempt. Nestlings per attempt calculated by – (overall nest survival rate *% nestling survival * [mean clutch size *% eggs hatched]).

Treatment and period	No. of nests	Daily failure rate	Overall nest survival rate	Mean clutch size	% eggs hatched	% nestling mortality (excl. whole-brood failure)	Nestlings per attempt
Control – early	16	0.033	0.478	3.25	84.62	3.23	1.272
Control – late	8	0.045	0.363	3.40	76.19	7.69	0.868
UP – early	21	0.031	0.500	3.53	81.13	8.70	1.308
UP – late	18	0.015	0.717	4.00	75.00	13.64	1.858
WSR – all nests	13	0.007	0.857	3.43	62.50	15.00	1.784

nests varied significantly with both treatment and period. Over the whole breeding period, the mean number of singing males and nests was greatest on UP, while WSR supported fewer territories and nests than the Control. On all treatments, the number of territorial males and nests decreased by June. Over the breeding season UP lost fewer territorial and nesting birds than the Control and, in the case of the territory model, still held equivalent numbers to those on the Control at the start of the breeding season in April. However, there was no significant overall effect of the period*treatment interactions in either the territory or the nest models. The extent of the reduction in numbers of territories between April and June was similar for WSR and the Control but WSR lost fewer nests than the Control between the early and late nesting periods. Productivity early in the breeding season was similar between the Control and UP. However, later in the breeding season UP nests produced an average of one more chick per attempt than those in the Control. Productivity in WSR was also high, although the sample was too small to divide by period (Table 3). Over the entire breeding season, daily nest failure rate (DFR) did not differ between the Control and UP. However, for late nests DFR was significantly higher in the Control than in UP (Wald = 4.34, *df* = 1, *P* = 0.037). There were too few data to analyse DFR in WSR. Individually, neither treatment nor period had a significant effect on nestling body mass. However, the interaction between treatment and period was significant. After controlling for nestling age, body condition decreased in the Control but increased in UP and WSR over the course of the breeding season. Treatment and the interaction between treatment and period both had significant effects on the ratio of foraging within and outside of the nest field. The proportion of within-treatment foraging flights decreased over time in the Control but remained constant in UP (Table 2). Foraging estimates for WSR should be treated with caution, as sample sizes were very small.

DISCUSSION

In 2002, UP conferred significant advantages for Skylarks over conventionally managed winter wheat in the Control treatment, with birds breeding for longer within the crop (the reduction in the numbers of territorial and nesting birds between early and late breeding season was about half that of the Control), combined with greater productivity and nestling body condition later in the breeding season. However, contrary to the original hypothesis that the vegetation structure and positioning of UP would provide a more easily accessible and safer nesting environment, there was little indication that Skylarks were selecting the actual patches for nesting. Instead, the main benefit of UP appeared to be as a foraging habitat. In later UP nests the maintenance of a high proportion of foraging within the nest-field, greater clutch size and better nestling body condition suggest that birds were finding sufficient food within the field. In contrast, in the Control, birds had to forage further away from the nest, with the associated costs to reproductive success and nestling fitness.

Coleoptera and Diptera were the most frequently recorded items in the nestling diet. The significantly greater species richness and abundance of certain species of Coleoptera in UP, compared with the other treatments and in the patches (PUP) compared with the adjacent crop (CUP), suggests foraging Skylarks could be responding to increased abundance of food. However, individual species numbers were so low that single species were unlikely to have contributed significantly to nestling diet (unless they were also of significantly larger or of better nutritional quality) and, over the treatment area as a whole, the total numbers of individuals did not differ significantly between the Control and UP. Moreover, PUP comprises such a small area (< 0.5%) of a field that they are unlikely to have increased food resources *per se* within the field. Perhaps more importantly, detection of and access to seed and invertebrate foods in the patches was probably easier where there was less vegetation and a greater amount of bare ground later in the breeding season. Odderskaer *et al.* (1997) reported selection of tramlines and natural bare areas within cereal crops by foraging Skylarks. Future SAFFIE research will study the use of the patches by foraging Skylarks and seek to determine relative importance of food abundance and accessibility.

Despite the lack of a shift of later nesting birds into patches, nest survival rates for later-nesting birds were higher in UP than in the Control. Although no direct evidence exists from this study, this may also be attributable to food availability, as reduced parental effort in nest-guarding for birds that forage further away from the nest or from hungry chicks being more vocal are both thought to result in increased predation (Evans *et al.* 1997, Brickle & Harper 2000). Although little is known about Skylark post-fledging survival rates, the greater body mass of UP (and WSR) nestlings immediately prior to leaving the nest may be indicative of an increased chance of survival, as this is known to be a significant predictor of subsequent survival in other species (e.g. Magrath 1991).

Benefits from WSR were less clear-cut, because although there were indications of greater productivity and nestling condition, rates of territory loss were similar to the Control and only a small number of nests were located (with all but one attempt concentrated on two Cambridgeshire sites). The relative lack of breeding Skylarks may be accounted for by either the generally low numbers of key invertebrate taxa from June onwards (although there were more Coleoptera in June than in the conventional crop) or the crop structure. Although the wider drill width meant that at ground level WSR had more bare earth than the UP crop, the vegetation structure was no different to the Control and less open and taller than in the patches. This supports observations by fieldworkers that suggested the canopy closure was almost complete in many of the WSR treatments by June. Interestingly, on the two sites with multiple WSR nests, sward height was shorter than on other WSR treatments ($Z = 2.63$, $df = 1$, $P = 0.008$). Crop variety and seed rate could be chosen to prevent canopy closure, while manipulation of herbicides could increase weeds that support invertebrate food. The GCT is currently examining these issues, while the latter also forms part of experiment 1.2 in SAFFIE.

Prolonging the breeding season and enhancing productivity in winter wheat could make major contributions to Skylark population recovery. Based on the productivity figures in Table 3 and observed nest densities, putting UP in all of England's wheat fields, at the density tested here, would increase nest productivity in wheat by 49% (assuming no change in density-dependent mechanisms, such as competition for nest-sites or predation, and a constant survival rate).

Preliminary results from 2003 also indicate that UP benefit breeding Skylarks. Agronomic assessment of UP suggest the option is easy for farmers to implement, and cheap (£3–8/ha, dependent on whether additional herbicide spot-sprays are necessary to control pernicious weeds). The Entry Level Scheme will include UP as a prescription and the suggested level of compensation should be sufficient to cover costs, even in scenarios where additional weed control is necessary. Together, these results suggest a cheap and effective solution that could lead to a significant recovery in Skylark populations.

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