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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: BD1448

2. Project title: Cereal-based whole crop silages: a potential conservation mechanism for farmland birds in pastoral landscapes.

3. Contractor organisation(s):
Royal Society for the Protection of Birds

Centre for Agri-Environment Research, University of Reading

Harper Adams University College

4. Total Defra project costs (agreed fixed price): £ 306,372

5. Project: start date .... 01 August 2003

end date .... 30 November 2007

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

1. Large declines in UK farmland bird populations have become a major conservation issue and the UK Government is committed to reversing these declines by 2020. Specialisation of farming enterprises has resulted in the disappearance of much arable cultivation from many pastoral areas of western Britain and this has probably been a major cause of farmland bird declines in these regions. Maize now accounts for most arable cultivation in lowland livestock regions but may be of limited value to farmland birds.

2. There is a large body of evidence demonstrating the importance of arable cultivation to farmland birds, particularly when crops are spring-sown and herbicide inputs are reduced. Benefits to birds include the provision of nesting sites from spring cultivation (e.g. lapwing, skylark), ripening grain as an important summer food often sustaining chicks during wet weather (e.g. buntings, sparrows, finches) and weed seed and spilt grain from winter stubbles (e.g. buntings, sparrows, finches, skylarks). In grass-dominated landscapes, cereal stubbles (from intensively managed crops) need to account for at least 10% of the land area to ensure stability of skylark and yellowhammer populations.

3. Cereal-based wholecrop silage (CBWCS) is an alternative form of preserved forage that has become increasingly popular among UK livestock farmers in recent years. The cereal crop is harvested before the grain is ripe and usually fermented in silage clamps. CBWCS provides a feed of consistent quality and predictable dry matter yield, can be grown anywhere in the UK and is much less susceptible to dry summer growing conditions than grass. Fermented wholecrop silage can tolerate a limited weed burden. While most CBWCS grown in the UK is currently winter wheat, all cereals can be ensiled in this way. Bi-cropping with pulses or brassicas can be employed to raise protein levels in feed. Farmers substituting CBWCS for some their grass silage rations can expect substantially increased dry matter intake (CBWCS are highly palatable to dairy cows), higher energy intake associated with the much higher starch levels, reduced rates of acidosis and increased health and fertility of dairy cows. However, unlike substitution of grass feed with maize, there is little evidence that substitution with CBWCS increases milk yields or quality. Limited evidence suggests that inclusion of CBWCS can increase liveweight gain among beef cattle (a 7% increase when CBWCS was included as 25% of the feed).

4. Our general aim was to assess the biodiversity benefits and agronomic costs and benefits of low-input CBWCS in a typical intensive lowland livestock region of England. We reviewed existing knowledge of the agronomic practicalities and costs of producing wholecrop silage and the potential nutritional implications of feeding CBWCS to livestock. We measured agronomic yields and feed quality of three CBWCS: winter wheat and spring barley grown with and without broad-spectrum herbicide application. We also assessed the relative biodiversity benefits (with respect to plants, invertebrates and birds) of these three CBWCSs plus grass silage and maize, the predominant silage crops grown by livestock farmers across most of lowland Britain. These five silage crops provided the main study treatments.

5. Biodiversity and agronomic data were collected from 16 livestock farms (mainly mixed dairy enterprises) in the West Midlands of England during the 2004-2006 growing seasons. On each farm, landowners were contracted to grow one field of autumn-sown wheat and one field of spring-sown barley (with a split-field herbicide treatment) on the same fields for two successive growing seasons. Farm entry into the study was staggered so that seven farms were contracted during the 2004 and 2005 growing seasons, with a further nine farms contracted during the 2005 and 2006 growing seasons.

6. Dry matter yield of the CBWCS was measured from fresh crop samples collected 1-2 days before harvest. Nutritive quality assessments were carried out on samples of ensiled feed held in net bags within silage clamps. Botanical recording was conducted at 2m and 30m from the crop edge in all five silage treatments during June, November and February in each year and distinguished between plants that were in vegetative and sexually reproductive states. Invertebrate abundance was assessed during June using Vortis suction samplers and sweep netting, also at 2m and 30m from the crop edge. Bird usage of treatment plots was measured using fixed duration (45 minute) watches followed by transect flush counts repeated eight times at each site during each summer and 5-7 times during each winter. Data were analysed using generalised linear mixed models that allowed for the spatial clustering of fields within farms and the non-independence of repeated measures on the same field plots on successive occasions. Bird data were grouped into ecologically distinct guilds to facilitate statistical analysis. One high priority conservation guild was the seed-eating passerines (or ‘granivores’) comprised mainly of yellowhammers (conservation status: red), chaffinches (green), tree sparrows (red) and house sparrows (red).

7. Yield of winter wheat wholecrop was substantially higher and less variable between years than either of the barley wholecrop treatments. The mean dry matter yield of (fermented) winter wheat was 14.1 t DM / ha (18.3 t DM / ha for crops harvested later for urea preservation) compared to 10.4 t DM /ha for barley treated with broad-spectrum herbicide and 9.2 t DM / ha for barley not treated with broad-spectrum herbicide. Mean annual wheat yields varied by only 7% during the three years of the study compared to 26% and 35% for the respective barley treatments. The quality of the wheat silage was generally higher than the barley (4.3% higher starch content, 2.1% higher D-value and 3.1% higher metabolisable energy) although the barley feed had marginally higher protein content.

9. Both barley treatments were strongly preferred by a wide range of farmland birds during summer and winter. The strong preference of granivores, skylarks and meadow pipits for barley stubbles probably reflects the relative abundance of reproductively active *Poa annua* and various forbs on that treatment. Usage of barley stubbles remained high throughout the winter despite a marked decline in the abundance and reproductive activity of most forbs by February. *P. annua* is one of the few plants to remain reproductively active during late winter and may be particularly important for seed-eating birds at this time of probable food shortage. The relatively heavy usage of summer barley by granivores, skylarks, gamebirds, insectivores and Hirundines reflects a combination of relatively high invertebrate biomass and the late summer grain resources associated with this crop.

10. Spraying of barley with broad-spectrum herbicide led to a modest increase in dry matter yield (ca. 12%) but had little or no impact on the abundance of weeds or invertebrates, or on bird usage during summer or winter. There was little evidence of any benefits to biodiversity of growing barley on the same field for two years in succession.

11. Although wheat fields were strongly avoided by most birds of conservation priority during winter, usage during summer was similar to that of barley fields. Autumn cultivation followed by winter or spring herbicide application probably account for the relative lack of forbs on wheat fields compared to other silage crops, while increasing grain and invertebrate resources probably account for late summer usage of wheat by some bird species.

12. Effective weed control rendered maize a relatively sterile crop with little forb or grass cover during summer and particularly during winter. A general lack of winter seed resources probably explains the low usage of maize stubbles by buntings, skylarks and meadow pipits, and a lack of weed cover probably explains the significantly lower invertebrate biomass in summer. Unhindered access to the ground during winter and early summer probably explains the relatively high levels of maize field usage by several ground-feeding insectivorous bird groups including thrushes, Corvids and small insectivores.

13. Grass fields were little used by most farmland birds (particularly conservation priority species and groups) during summer or winter, and this probably reflects a severe lack of forbs and reproductively active grasses. The only groups that favoured grass as a foraging habitat were soil-invertebrate feeding species like thrushes and Corvids. The strong avoidance of grassland during summer by small insectivorous birds is contrary to the moderately high densities and biomass of a range of suitable invertebrate prey and may reflect limited accessibility of invertebrate prey in the tall, dense silage swards.

14. Encouraging livestock farmers to grow CBWCS (preferably without the application of broad-spectrum herbicide) and leaving stubbles undisturbed through the following winter should significantly enhance summer and winter food resources for a range of farmland birds of high conservation priority. Spring-sown CBWCS will also provide suitable nesting habitat for priority species like lapwing and skylark. To improve the suitability of the farmed landscape for farmland birds, CBWCS should replace crops that currently provide little in the way of food or safe nesting habitat like maize and improved grassland. However, replacing low-input traditional methods of cereal production (such as reaper-binder harvesting followed by outdoor stacking) with CBWCS could reduce feeding and nesting opportunities for farmland birds.

15. Production costs of CBWCS (£43-62 / t DM) are considerably lower than those of grass silage (ca. £77 / t DM) and similar to those of maize (ca. £52 / t DM). The high and predictable yields of winter wheat make this the most attractive wholecrop cereal option for livestock farmers (ca. £50 / t DM), the equivalent costs for spring barley wholecrop being about 15% higher (ca. £58 / t DM). Growing spring barley wholecrop without the use of broad-spectrum herbicide reduced yield by 13% and increased production costs by 6% (ca. £61 / t DM).

16. Farmers in England can now receive payments through the Entry Level Scheme (ELS) to grow up to 5 ha of CBWCS each year. No broad-spectrum herbicide can be used and following stubbles must be left *in situ* through the following winter. The payments available on these 5 ha of CBWCS reduce the farmers production costs by approximately 40% for spring barley (from ca. £61 / t DM to ca. £36 / t DM) and by an estimated 33-37% for winter wheat (depending on the reduction in yield from not using broad-spectrum herbicide).

17. Thus, the production of CBWCS is a financially viable option for livestock farmers and with ELS payments should be financially attractive. There is an urgent need for more effective knowledge transfer to farmers with respect to the relatively predictable yields, modest production costs and the nutritive benefits of feeding CBWCS to livestock. Further research is warranted to identify and reduce the main barriers deterring livestock farmers from growing cereals for wholecrop production including the low uptake of CBWCS options within ELS agreements.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

1. Background & Objectives

The overall aim of the project was to assess the relative biodiversity and agronomic benefits of four livestock silages that are widely grown in the UK: grass, maize, wheat for wholecrop and spring barley for wholecrop. The interest in cereal-based wholecrop silages is based on a growing body of evidence that cereals produced with reduced pesticide inputs can provide food-rich habitats favoured by a suite of priority farmland birds during summer and winter (Rands 1985, Moreby & Southway 1999, Brickle *et al*. 2000, Morris *et al*. 2005). In pastoral-dominated landscapes, the local area of arable cultivation is a positive predictor of local breeding densities of a range of seed-eating farmland birds (Robinson *et al*. 2001). Moreover, the area of cereal stubbles left uncultivated over winter is positively associated with trends in breeding populations of skylark *Alauda arvensis* and yellowhammer *Emberiza citrinella* with 20 ha or more stubble needed per 1 km square to maintain population size (Gillings *et al*. 2005). Thus, encouraging cereal production (especially low intensity production followed by winter stubbles) in livestock dominated regions has the potential to maintain and enhance local farmland bird densities. Thus in the UK, the encouragement of cereal-based wholecrop silage (CBWCS) has a potential role to play in the delivery of the UK Government's Public Service Agreement H13 for the reversal of wild bird population declines, as well as enhancing farmland biodiversity more generally.

The specific objectives of this study were:

1. To review existing knowledge of the agronomic and economic costs and benefits of cereal-based whole crop silages (CBWCS) within different livestock systems, and to identify possible constraints over the adoption by farmers of low-input CBWCS.
2. To assess the agronomic practicalities, yields and costs of growing winter wheat and low-input spring-sown barley as whole crop silages within dairy farming systems.
3. To assess the invertebrate and seed resources (bird food) provided by winter wheat and low-input spring-sown barley whole-crop silage within dairy farming systems.
4. To assess the benefits of whole crop silage fields for nesting and foraging farmland birds.
5. To review the likely utility and costs of cereal-based whole crop silages as a potential agri-environment measure.

All of these objectives were met.

2. Methods

2.1 Literature review. A 35 page literature review (Lewis 2004) was submitted to Defra in December 2004. The Executive Summary is included here as Appendix 1 (see 'BD1448 – Appendices' document attached).

2.2. Study design. Biodiversity and agronomic aspects of wholecrop cereal production were assessed on 16 farms in the West Midlands of England between the growing seasons 2004 and 2006. The 16 farms were located in North Shropshire, South Cheshire and West Staffordshire. The predominantly medium to heavy loam soils with a mean annual rainfall of around 650-700mm provide suitable growing conditions for a range of crops. All 16 farms were primarily engaged in livestock production (15 dairy enterprises with arable components and one beef unit) and all had prior experience of growing cereals for wholecrop silage. Fifteen of the 16 farms were located within the area encompassed within a triangle delimited by Knutsford in the north, Stafford in the east and Shrewsbury in the south-west, the remaining site being located 15km west of Shrewsbury.

On each farm, landowners were contracted to grow one field of autumn-sown wheat and one field of spring-sown barley on the same fields for two successive growing seasons. Farm entry into the study was staggered so that seven farms were contracted during the 2004 and 2005 growing seasons, with a further nine farms contracted during the 2005 and 2006 growing seasons. Thus, the total number of farms engaged in the study was seven, sixteen and nine during the 2004, 2005 and 2006 growing seasons respectively.

The wheat treatment involved autumn sowing on the same field for two years in succession and there were no restrictions on pesticide and herbicide applications. Most wheat crops received applications of fungicides, herbicides, insecticides (mainly aphicides) and growth regulators. Wheat was typically sown between late September and mid-November, and harvested for wholecrop during mid-July. Barley fields were subjected to two separate herbicide treatments on a split-field design. The entire field was sprayed with a narrow-spectrum herbicide containing the active ingredient amidosulfuron (usually products 'Eagle' or 'Pursuit' at a rate of 25-40g/ha) during late April or May. This product is recommended by Defra for use on low-input agri-environment cereal options. Half of the barley field was subsequently sprayed with a broad-spectrum herbicide typically between late April and mid-June (popular products including 'Calibre', 'Quantum', 'Harmony M' and 'Jubilee'). Most barley fields also received applications of fungicide and some received growth regulators but insecticides were applied to only 3 of the 32 crops. Barley crops were typically drilled between late February and early April and harvested during mid-July. Barley stubbles were left clean and undisturbed until late February of the following year when fertilizers and slurry could be applied. On one barley field, a broad-spectrum herbicide ('Roundup') was used to control a severe ryegrass *Lolium perenne* infestation just prior to the sowing the second barley crop. Most of the cereal crops were sown and harvested by contractors.

Farms were selected that also provided fields of maize and grass grown for silage. The latter were ley grass fields most of which were dominated by perennial ryegrass and cut twice for grass silage before being aftermath grazed. Thus, the study considered the following five main treatments (plus abbreviations):

1. spring barley wholecrop treated with narrow spectrum herbicide with following winter stubble (BAR-MIN)
2. spring barley wholecrop treated with broad- and narrow- spectrum herbicide with following winter stubble (BAR-BS)
3. winter wheat wholecrop treated with broad-spectrum herbicide (WHEAT)
4. maize with following winter stubble (MAIZE)
5. ley grassland managed for silage (two-cuts then aftermath grazed) (GRASS)

Mean (and range) treatment field areas (ha) were barley: 4.4 (2.0-6.8), wheat: 5.3 (2.1-11.8), maize: 6.1 (1.4-16.4), grass: 6.5 (2.1-21.0).

2.3 Agronomic measurements. Herbage yield and a range of nutritive feed quality assessments were made for all three wholecrop cereal treatments. Above ground dry matter yield was assessed 1-2 days before harvest by collecting four fresh crop samples (all vegetation within 0.7 x 0.7m quadrats cut 8cm above ground level) at eight regularly distributed locations spread across each wheat field and at twelve regularly distributed locations spread across each barley field (six locations in each herbicide treatment). During the three years of the study, this pre-harvest sampling was undertaken between 7 July and 9 August. Fresh yield was recorded and dry matter content determined by oven drying samples at 105^{o}C until constant weight was achieved. Dry matter (DM) yield and percentage DM content were calculated.

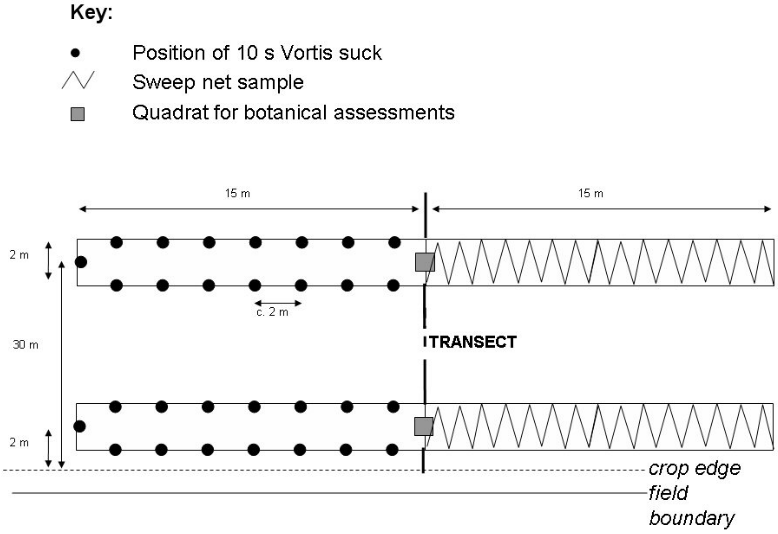
Nutritive quality assessments were undertaken on ensiled samples of the three treatments retrieved from farm clamps or storage bags. Three separate silage samples were sealed in labelled net bags and ensiled within each of the three treatments at each farm. Assessments included oven dry matter (%), crude protein (%DM), ash (%DM), starch (%DM), digestibility D-value (%DM), neutral detergent fibre (%DM), ammonium nitrogen (% of total nitrogen), metabolisable energy (ME) (MJ/kg DM) and pH. Silage samples were retrieved from farms when the silage was utilised for feed. Most silages were utilized between late September and mid-December with a few delayed until February or March. Several relatively late harvest dates were a consequence of urea-based preservation techniques being adopted (which requires a more mature cereal stage) on one farm in 2004, two in 2005 and one in 2006. All other CBWCS silages in this study were preserved using fermentation techniques.

2.4 Biodiversity assessments. Quantification of botanical composition and invertebrate abundance was determined from eight 30m transects in each replicate field (crop). These were positioned to provide information on differences between the field edge and field centre, and to coincide with the timed watch plots used for bird observations (below). Where possible, the distance between transects was a minimum of 30m and a maximum of 50m. At internal field corners, a minimum of 30m was maintained between the field centre sample positions of adjacent transects, even where this resulted in distances between transects at the field edge of greater than 50m.

Botanical assessments were carried out three times a year in June, November (2004-2006) and February (2005-2007) using 0.75m x 0.75m quadrats. From each transect, one quadrat was sampled at a distance of 2m from the crop edge and one at a distance of 30m. For each quadrat, total percentage cover (non repetitive cover by vertical projection) was recorded for (a) crop (maize, wheat and barley only), (b) Graminoids, (c) forbs and (d) bare ground. Percentage cover was also recorded for all vascular plant species according to whether individuals were present as either solely vegetative or sexually reproductive. Plant nomenclature follows Stace (1997).

For each transect, two methods of collection were employed to sample key invertebrate groups during June: suction sampling and sweep netting. A Vortis suction sampler (Burkhard, Rickmansworth, UK) was used to collect insects from each transect at distances of 2m and 30m from the crop edge. At each sampling position, 10 second suck samples were collected from 15 regularly spaced positions within a 2m x 15m area (with approximately 2m between each position) and the samples pooled. Sweep net samples were collected using a standard D-frame kite net (Watkins & Doncaster) from a 2m x 15m area opposite to that used for suction sampling (Fig. 1). Each sample comprised 30 pooled sweeps taken at approximately 50cm intervals within each 2m x 15m area.

Figure 1. The spatial arrangement of botanical and invertebrate sampling positions for each transect.



Invertebrate groups were identified to order (or to family/suborder for the Coleoptera, Hymenoptera and Hemiptera) and within each group classified into three body size classes (a) 2-5mm, (b) 6-10mm and (c) >10mm. Prey smaller than 2mm in length were judged unimportant in the diets of most farmland birds, while larger prey were likely to have been nutritionally more important than smaller prey (Evans *et al*. 1997). The number of individuals for each was recorded according to sampling technique. To provide a further indication of bird food value, total biomass was determined for each sample by pooling all individuals and weighing after drying at 70°C for 48 hours.

Bird usage of experimental plots was assessed using fixed duration watches (each lasting 45 minutes) of clearly defined plots within treatment fields. The area and extent of these timed watch plots (TWPs) varied according to topography and boundary features (mean and range TWP areas (ha): BAR-MIN: 1.98, 0.70-2.98; BAR-BS: 1.98, 0.88-3.20; WHEAT: 3.21, 0.95-5.15; MAIZE: 3.04, 1.36-6.81; GRASS: 3.31, 1.59-6.08). Boundaries of TWP's were marked with canes to facilitate bird usage observations. Fixed duration bird watches were conducted from a fixed vantage point which was usually adjacent to a field boundary. Our main measure of plot usage intensity was the number of visits made by each bird species to the TWP during the 45 minute watch period. To achieve this observers noted the time and number of individuals seen entering or leaving the plot. This allowed us to estimate the minimum number of individuals using each plot as well as the total amount of usage (i.e. the number of bird visits made to each plot). These counts were split between the field headland (within 10m of the field boundary) and the field centre. After the 45-minute observation period, a flush count was conducted of the entire plot. This involved the observer walking around the entire margin of the treatment plot and then walking parallel transects spaced to ensure all points in the field were within 30m of the observer. All birds flushed off the field were recorded, taking care to distinguish birds on and off the TWP.

Eight sets of fixed duration watches were conducted on each treatment field on each farm during each of the three summers (April-July) which entailed 256 separate farm visits. Seven sets of watches were conducted on each farm during the first and third winters (November-February) with five watches being conducted during the second winter when the full compliment of 16 farms was operational (entailing 192 separate farm visits). On the vast majority of farm visits, bird usage watches were conducted on all five treatment plots (the treatment order of watches being randomised between visits) but a few watches of maize fields were abandoned during April and May because the fields had not been sown.

For ground-nesting species like lapwing, we note the numbers of pairs showing evidence of nesting on and off the TWP during the timed watch and on the flush count. Casual records are also collected of breeding behaviour on the experimental fields but off the TWPs. Nesting evidence included nest building, incubation, feeding chicks or fledglings and removing faecal sacs.

2.5 Data analysis. All data were analysed using generalised linear mixed models (GLMMs) in which 'farm' and 'farm' x 'year' were declared as random factors, while 'year' (or summer/winter) and 'treatment' (and their interaction) were declared as fixed factors. GLMM's are an efficient method for analysing unbalanced data where the sampling units (fields) are spatially clustered (Milsom *et al*. 2000). Analyses took account of several treatment errors most notably three cases where broad-spectrum herbicide was applied to the wrong side of the barley field, and two cases where barley treatments received broad-spectrum herbicide. One barley field received no broad-spectrum at all. Any fields treated with herbicide within 21 days of botanical/invertebrate surveys were excluded from analyses of those data.

The agronomic data were approximately normally distributed and were analysed using a GLMM in which 'farm', 'farm'x'year' and 'farm'x'treatment' were declared as random factors and normal errors were assumed. The number of months the silage was left in the clamp was included as a fixed covariate in all analyses of silage quality measures.

Botanical data (natural logarithm transformation of count plus one; angular transformation for bare ground cover) were analysed using normal errors GLMM's with 'treatment', 'year', 'distance' from field edge (2m vs. 30m) and 'month' (June, November, February) and 'treatment' x 'month' as fixed effects. If the latter interaction was not significant it was removed from the model. 'Farm' and 'farm' x 'year' were declared as random effects. Serial correlation between vegetation scores recorded on the same treatment plots (=subjects) on successive sampling occasions was modelled using a variable 'time' specified as a repeated measure with an autoregressive covariance structure. 'Time' was a three level factor used to account for differences in the timing of cultivation between treatments. Thus, for winter wheat, time was set to 1 for November, 2 for February and 3 for June, while for the other crops time was set to 1 for June, 2 for November and 3 for February. The factor 'year' included samples collected during June, November and the following February.

Invertebrate data (natural logarithm of count plus one) were also analysed using GLMM's with fixed 'treatment' and 'distance' effects, with 'farm' and 'farm' x 'year' interaction as random effects. Repeated sampling of treatment plots over successive years was modelled by declaring 'year' as a repeated measure, with plot/field as the subject and declaring an autoregressive covariance structure. An interaction between invertebrate size category and treatment was used to test for differences in invertebrate sizes between treatments.

To investigate whether vegetation or invertebrate communities differed systematically between spring barley treatments in their first and second years, the term "crop age" rather than year was used to indicate whether the barley crop was the first or second to be grown in a particular field. In these analyses the interaction between ‘treatment’ and ‘crop age’ replaced the ‘treatment’ by ‘month’ interaction. The selection of key plant species was based on their importance in the diets of farmland birds (Wilson *et al*. 1999, Holland *et al*. 2006, D. Buckingham RSPB, *pers. comm.*) and their overall frequency of occurrence in the samples. Plant and invertebrate groups/species were selected for analysis if present in at least 5% of fields over the entire three-year sampling period.

Bird usage data were too sparse to allow separate analyses for most species. Thus, with a few exceptions, data were aggregated across species having similar diets and foraging habitat requirements. These groups were granivores (finches (mainly chaffinch *Fringilla coelebs*), buntings (mainly yellowhammer), sparrows (similar numbers of tree and house sparrow *Passer montanus* & *P. domesticus*), insectivores (mainly meadow pipit *Anthus pratensis*, pied wagtail *Motacilla alba*, robin *Erithacus rubecula* and dunnock *Prunella modularis* plus other wagtails, chats, wren *Troglodytes troglodytes*, warblers & tits), Hirundines (mainly swallow *Hirundo rustica* plus swift *Apus apus*, house martin *Delichon urbica* and sand martin *Riparia riparia*), thrushes (mainly blackbird *Turdus merula*, starling *Sturnus vulgaris* and fieldfare *T. pilaris*), Corvids (mainly jackdaw *Corvus monedula*, rook *C. frugilegus*, carrion crow *C. corone* and magpie *Pica pica*), gamebirds (mainly pheasants *Phasianus colchicus* and red-legged partridges *Alectoris rufa*) and pigeons & doves (woodpigeon *Columba palumbus* and stock dove *C. oenas*). Aggregate counts of farmland birds over the three years of the study are summarised in Appendix 2.

Summer and winter bird usage data were analysed separately. Many farmland birds exhibit flocking behaviour in winter but are essentially solitary or territorial during summer. Consequently winter farmland bird count data are often highly overdispersed unlike summer count data for which the Poisson distribution often provides a reasonable fit. Although our summer count data were moderately overdispersed (extra-dispersion coefficients ranged between 1.2 and 8.1) this could be allowed for by declaring a Poisson error structure and inflating variances according to the extent of overdispersion (Littell *et al.* 1996). However, the winter data were highly overdispersed (extra-dispersion coefficient typically between 10 and 60) so we analysed variation in the frequency of occurrence of target bird species/groups across the multiple field usage surveys. Thus, each species or guild was considered present or absent during each winter survey and a binomial error structure was adopted.

Repeated measures GLMM’s were adopted to reflect the design of multiple bird surveys repeated on the same plots within winters or summers. Checks indicated little evidence of serial correlation in summer counts (or winter presence/absence scores) and a simple compound symmetry covariance structure was adopted in which counts (or presence/absence scores) from the same treatment plot in the same season (i.e. a ‘plot’x’year’ factor) were assumed to be correlated with each other. Thus, the GLMM included random ‘farm’ and ‘plot’x’year’ factors plus, where the data allowed (i.e. the model converged), a ‘farm’x’year’ term. Fixed factors included ‘year’, ‘treatment’ and ‘year’x’treatment’, plus a two-level early-late season factor and its interaction with treatment. These early-late terms tested for differences in the intensity of treatment usage between the first and second halves of the respective seasons. In addition, we screened a set of potential ‘nuisance’ covariates that might have influenced usage of treatment plots by birds. These nuisance variables included time of day the survey was conducted (early, middle or late), field area, TWP area (winter models only as the logarithm of field area was included as an offset in all the summer Poisson models), an index of field enclosure (Wilson *et al.* 1997) calculated at both the field and TWP scales, and the number of internal right angles within the TWP. These were only retained in GLMMs if they were statistically significant predictors of plot usage by birds. We also tested for potential differences in bird usage between barley crops in their first and second growing seasons by adding a three level barley age fixed factor to GLMMs (where 0=second year BAR-MIN, 1=second year BAR-BS and 2=all other crops). Year was retained in these GLMMs and we included an interaction between the barley age and early-late factors.

In a further set of analyses on the same bird groups we tested for relationships between the intensity of field usage by birds and associated food resources as measured during botanical and invertebrate assessments (above). Six potential measures of bird food abundance were screened using similar repeated measures GLMM’s to those described above: cover of total grass, forbs and *P. annua* plus cover of reproductively active grass, forbs and *P. annua*. The summer bird usage data were also screened against the sum of the total invertebrate biomass sampled using sweep nets and Vortis samplers (although some aerial feeders were screened only against the sweep net data while some ground-feeding groups were screened only against the Vortis data). The winter vegetation data were averaged across the two sampling occasions (November and February) prior to analysis. Each bird group was classified as foraging primarily on the margins of fields (>70% of observations within 10m of the field boundary), in field centres (<20% of observations within 10m of the field boundary) or across the whole field (20-70% of observations within 10m of the boundary). Bird usage data were then analysed according to the appropriate botanical and invertebrate data (i.e. field margin groups in relation to vegetation and invertebrate data collected 2m from field boundaries, field centre groups in relation to vegetation and invertebrate data collected at 30m from field boundaries, and whole field groups in relation to the average vegetation cover and invertebrate abundance at 2m and 30m). Each of the six or seven covariates (COV) was assessed by fitting the following fixed effect terms after allowing for any significant nuisance variables and a three-level winter/summer factor (YEAR): $\mathrm{COV} + \mathrm{COV}^2 + \mathrm{YEAR}*\mathrm{COV} + \mathrm{YEAR}*\mathrm{COV}^2$.

In all GLMM's, degrees of freedom were calculated using the iterative Satterthwaite's method (Schabenberger & Pierce, 2002). When a factor was significant and not part of an interaction, *post-hoc* pairwise comparisons ($P = 0.05$) were made to investigate differences between factors. Although application of the sequential Bonferroni correction reduces the probability of a spurious result being obtained when analysing multiple responses, it was not applied owing to the inflation of Type II errors (Moran, 2003). All mixed models were fitted using Procedures MIXED and GLIMMIX in SAS Version 9.1 (Littell *et al*. 1996).

3. Results.

3.1. Crop yield and silage quality.

Most of the crop yield and quality measurements varied significantly between the three crop treatments and between years, and in many cases year effects differed between treatments (i.e. significant treatment x year interactions) (Appendix 3). Overall yield differed significantly between treatments ($P<0.001$) with WHEAT yields averaging 4.25 t DM/ha higher than those of BAR-BS ($P<0.0001$) and 5.4 t DM/ha higher than BAR-MIN ($P<0.0001$) (Fig. 2a). Application of broad-spectrum herbicide increased barley yield by an average of 1.15 t DM/ha the difference being almost significant ($P=0.066$). Annual variation in yield was much greater in both barley treatments than in the more predictable and higher yielding wheat treatment (Table 1). Although variation in percentage dry matter yield (Table 1) was almost significant across treatments ($P=0.076$), the only significant paired difference was that between WHEAT and BAR-MIN ($P=0.024$). Significant 'year' and 'year*treatment' terms reflected relatively low %DM for barley crops grown in 2005 (Table 1).

Table 1. Mean (across sites, and standard error) crop yields and % dry matter (DM).

Treatment	2004 (7 farms)		2005 (16 farms)		2006 (9 farms)		Least Square Means (32 farm years)	
	Yield t DM/ha	DM (%)	Yield t DM/ha	DM (%)	Yield t DM/ha	DM (%)	Yield t DM/ha	DM (%)
BAR-MIN SE	10.5 (0.75)	48.1 (3.38)	9.5 (0.57)	40.5 (2.89)	7.8 (0.78)	44.7 (3.14)	9.2 (0.59)	44.4 (2.79)
BAR-BS SE	12.2 (0.81)	50.7 (3.42)	9.7 (0.69)	42.2 (2.86)	9.7 (0.49)	50.1 (3.13)	10.4 (0.59)	47.7 (2.80)
WHEAT SE	14.8 (1.14)	45.3 (3.25)	14.6 (0.95)	47.4 (2.85)	14.5 (0.94)	56.0 (3.09)	14.6 (0.58)	49.5 (2.77)

All silage quality measures except dry matter differed significantly between treatments, the differences lying entirely between the wheat and barley treatments (Appendix 3). There were no significant differences in any of the silage quality measures between barley treatments. Mean treatment values (averaged across years and farms) are presented in Table 2 and Fig. 2b-d. Although there was no difference in the dry matter content of the three silages, WHEAT silage provided significantly higher starch content, D value, ME and ammonium, and significantly lower protein, ash and digestible fibre content and ph than the barley silages (Table 2, Fig. 2b-d). Several of the silage quality measures changed significantly with time spent in the silage clamp. DM, ash, fibre and pH all increased significantly with time spent in the clamp while D–value and ME declined over time.

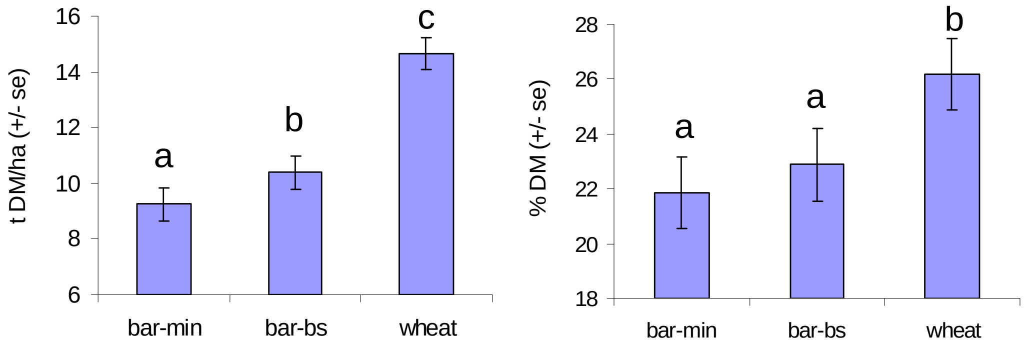
Table 2. Mean (across sites and years, and standard error) silage quality measures.

Treatment	DM content (%)	Starch (%DM)	Protein (%DM)	Ash (%DM)	D value (%DM)	ME (MJ/kg DM)	D fibre (%DM)	Ammonium (% N)	pH
BAR-MIN SE	50.7 (3.52)	22.9 (1.32)	11.3 (0.38)	5.34 (0.24)	61.4 (0.56)	9.71 (0.09)	47.6 (1.00)	8.72 (0.66)	5.3 (0.20)
BAR-BS SE	51.2 (3.51)	21.9 (1.31)	11.2 (0.37)	5.05 (0.24)	60.6 (0.56)	9.60 (0.09)	48.7 (0.99)	8.43 (0.66)	5.3 (0.20)
WHEAT SE	52.3 (3.51)	26.2 (1.32)	10.4 (0.38)	4.53 (0.24)	62.7 (0.57)	9.91 (0.09)	45.6 (1.00)	10.55 (0.67)	5.0 (0.20)

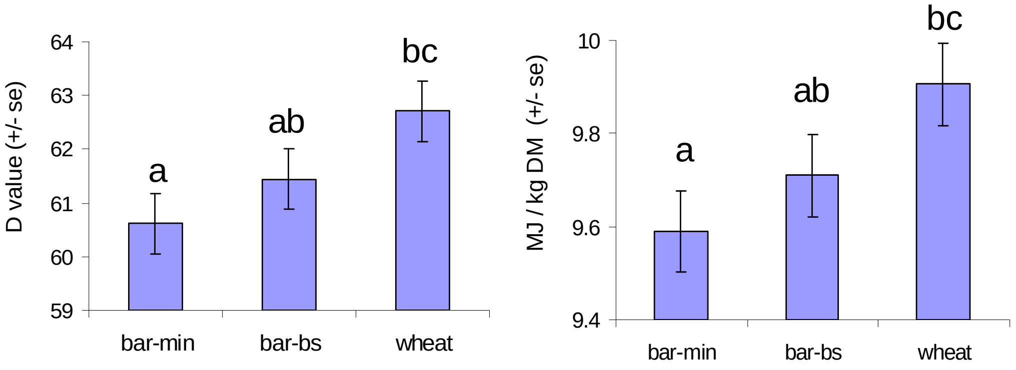
3.2 Weed burdens in following crops. Visual inspections along transects in crops following our wheat and barley wholecrop cereals conducted during May/June showed no extensive weed infestations that might have been a consequence of preceding crop management. The weeds present were patchily distributed across the field. Variability in species and distribution was wide and in several cases were probably related more to other field characteristics like drainage and soil type rather than recent management history. The patchy distribution of weeds made quantitative assessments difficult. There were no obvious visual differences in either weed infestation or crop height between the two sides of the field that had previously contained the split-field barley treatments.

Figure 2. Least squares mean, and standard error, silage yield and quality measures as derived from GLMMs. Treatments with the same letter do not differ significantly from one another.

(a) Mean yield at harvest (b) Starch content of silage



(c) D value of silage (d) Metabolisable energy



3.3 Botanical assessments.

3.3.1. General responses. The extent of crop cover, total grass cover, total forb cover and bare ground all varied significantly between treatments and months with a significant treatment*month interaction (Table 3). Seasonal variation in crop cover reflected seasonal variation in crop husbandry. The cover of spring-sown treatments (barley and maize) was much higher in June than during winter although volunteer barley was relatively extensive (Fig. 3a). Cover of winter wheat was more uniform across seasons (Fig. 3a). Crop cover was significantly lower at the edges of fields. Averaged over all treatments (excluding grass), years and months, cover values were 26.9% (± 2.3) and 30.9% (± 2.7), at 2m and 30m respectively.

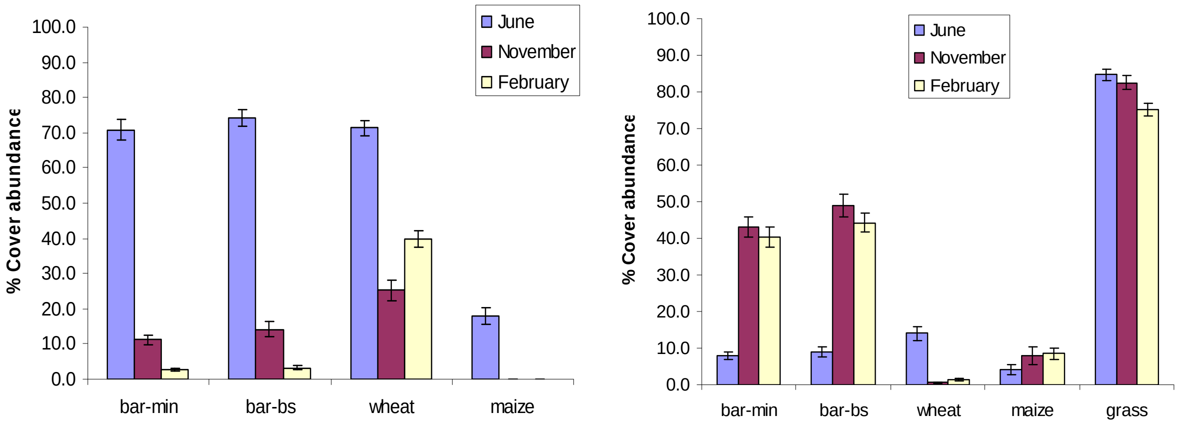
Table 3. Responses of general cover values according to treatment, distance, month and year. * = *P*<0.05, ** = *P*<0.01, *** = *P*<0.001, ns = non-significant at *P*>0.05.

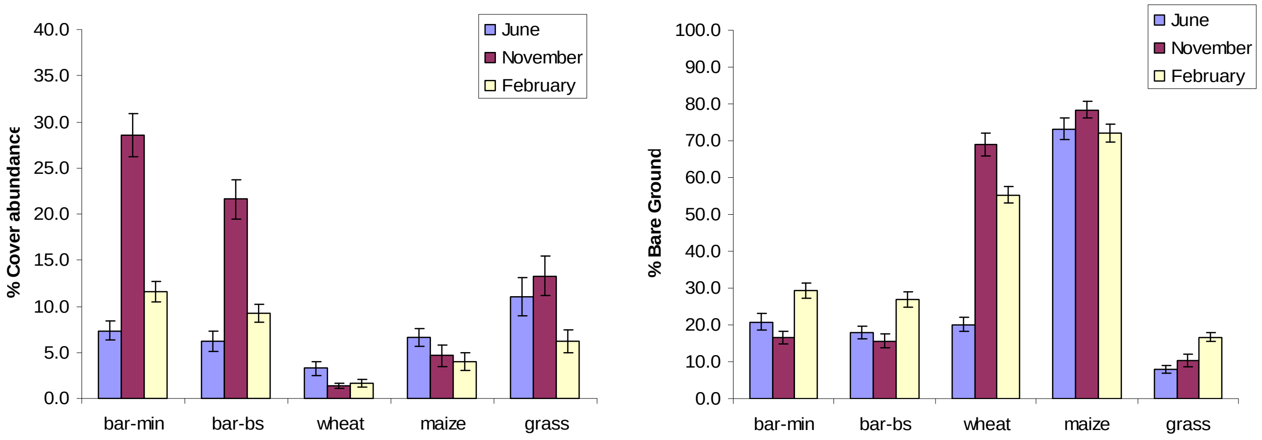
Cover	**Treatment**	**Distance**	**Month**	**Year**	**Treat. x Month**
Crop (excl. grass ley)	$F_{3,56.2} = 181.5$***	$F_{1,524} = 4.5$ *	$F_{2,135} = 438.1$ ***	ns	$F_{6,127} = 29.3$***
Total Grass	$F_{4,60.8} = 180.5$***	$F_{1,693} = 23.9$ ***	$F_{2,176} = 32.7$ ***	$F_{2,18.8} = 9.9$ **	$F_{8,176} = 73.1$***
Total Forb	$F_{4,61.1} = 13.3$***	ns	$F_{2,146} = 25.6$ ***	$F_{2,16.3} = 10.0$ **	$F_{8,148} = 14.6$***
Bare Ground	$F_{4,68.3} = 107.5$***	ns	$F_{2,155} = 36.8$ ***	ns	$F_{8,151} = 14.6$***

Grass cover was greatest in November and February for both spring barley treatments and for maize (Fig. 3b). Grass cover in wheat was greatest in June and remained low throughout the winter. Grass cover remained high throughout the year in grass fields, and did not differ significantly between the two barley treatments. Grass cover also varied significantly between calendar years (2006>2004=2005) and was greater at two metres from the crop edge compared to 30m (means of 33.1% (± 1.6) and 30.2% (± 1.5) respectively).

Forb cover was lowest in wheat during all months of assessment, and was highest in both barley treatments during winter (Fig. 3c). Forb cover also differed between calendar years (2006>2004>2005) but not between the field centre and two metres from the crop field edge. The extent of bare ground was generally lowest in grass leys and highest on maize fields (Fig. 3d). Within the three cereal treatments, bare ground was similar during summer and higher in wheat fields during winter. Bare ground increased on barley fields through the winter. The extent of bare ground did not differ between the edge and centre of crops or between years (Table 3).

Figure 3. Variation in mean (+/- se) crop, grass, forb cover and bare ground between treatments and months.


(a) Crop cover (b) Grass cover

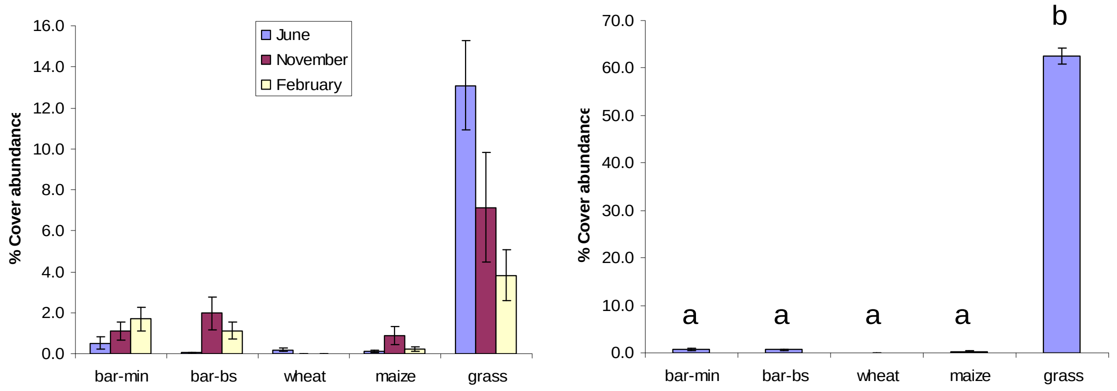

(c) Forb cover (d) Bare ground

3.3.2. Responses of key species. Of 25 forb species and 8 grass species selected as being an important resources for farmland birds, 23 forbs and 7 grasses responded significantly to at least one of the factors investigated (treatment, distance, month and year) (Table A.4.1; Appendix 4). No significant treatment effects were found for the forbs *Matricaria recutita* and *Sinapis arvensis* or the grass *Avena fatua*. The majority of responses involved significant month and treatment effects, with relatively few year effects. Treatment and month effects for the four most abundant grasses, annual forbs and biennial/perennial forbs are shown in Figures 4-6.

Cover of *Lolium multiflorum* was far greater in grass than in any other treatment, and was greater in barley than in wheat and maize (Fig. 4a). *Lolium perenne* dominated grass fields but was scarce in other treatments (Tukey test, $P < 0.05$) (Fig. 4b), while *Poa trivialis* was commonest in grass leys and barley but scarce in wheat and maize (Fig. 4d). *Poa annua* was most abundant in winter barley crops and virtually absent from wheat fields during winter (Fig. 4c). During summer *P. annua* was most common on cereals and least common on grass fields. Cover of *Holcus lanatus*, *P. annua* and *P. trivialis* were all significantly more abundant 2m from the field boundary than at 30m into the crop. The significant year effect for *P. annua* reflected a greater cover in 2006 than in 2005.

Chenopodium album cover was greatest in June in barley and maize treatments (Fig. 5a). *Stellaria media* and *Viola arvensis* were commonest on barley stubbles during November although abundance had fallen markedly by February (Fig. 5b & 5d). *Veronica persica* was most abundant in barley and least abundant in grass fields (Fig. 5c), and reached peak abundance in November. Six of the eight significant distance effects for forbs involved higher abundance 2m from the field boundary (the exceptions to this being *Fumaria officinalis* and *S. media*). The biennial *Cirsium vulgare* was much more abundant in barley than in any other treatment particularly during winter, and the difference between the two barley treatments was not significant (Tukey test, $P > 0.05$) (Fig. 6a). *Rumex obtusifolius* and *Taraxacum officinale* were most abundant on barley (especially during November) and on grass (especially during June) (Fig. 6b & 6c). *Trifolium repens* was much commoner on grass than on any other treatment, although abundance increased on barley and maize during winter (Fig. 6d).

Figure 4. Percentage cover (means ± se) of the four most abundant grass species according to treatment and month. The treatment x month interaction was not significant for *L. perenne*, so only treatment effects are presented (treatments with same letter do not differ significantly from one another).


(a) *Lolium multiflorum* (b) *Lolium perenne*

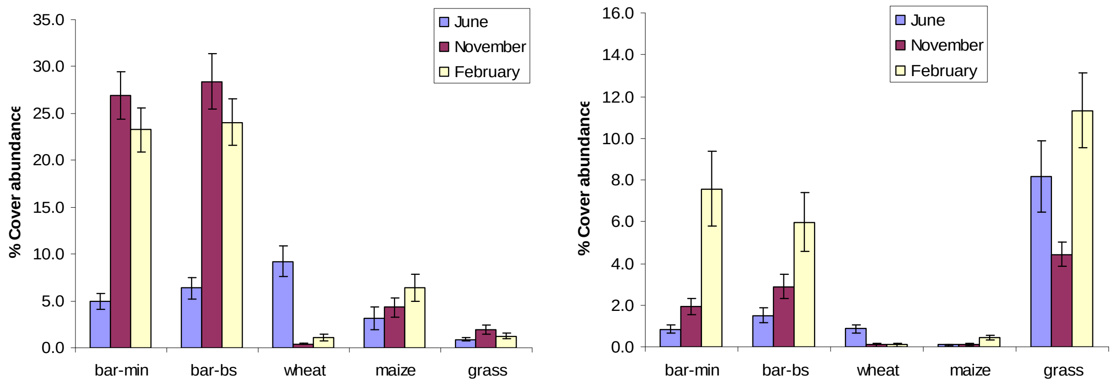
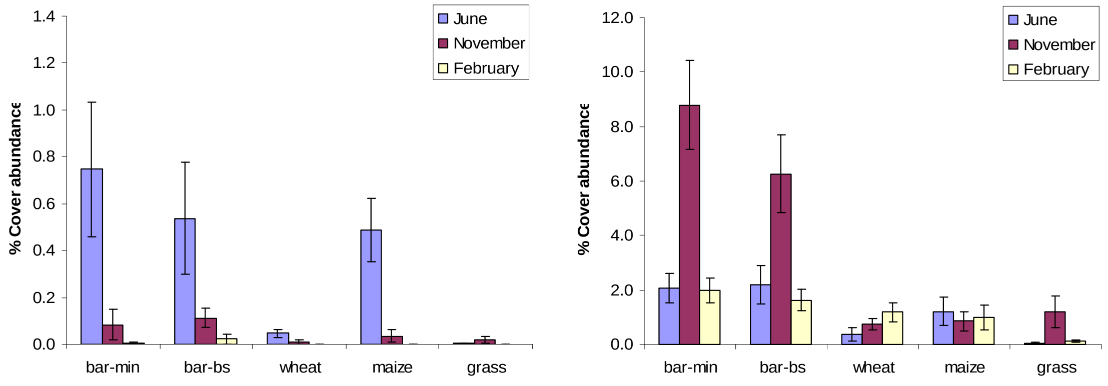

(c) *Poa annua* (d) *Poa trivialis*

Figure 5. Percentage cover (means ± se) of the four most abundant annual forb species according to treatment and month. The treatment x month interaction was not significant for *V. persica*, so only treatment effects are presented (treatments with the same letter do not differ significantly from one another).


(a) *Chenopodium album* (b) *Stellaria media*

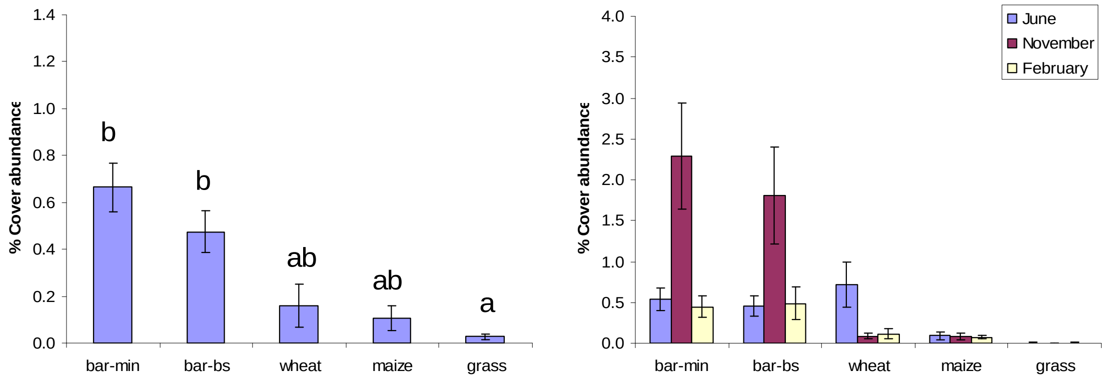
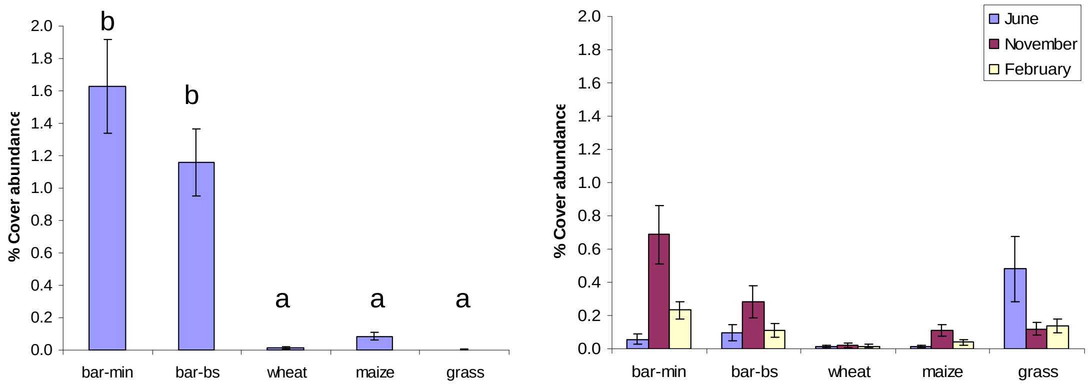
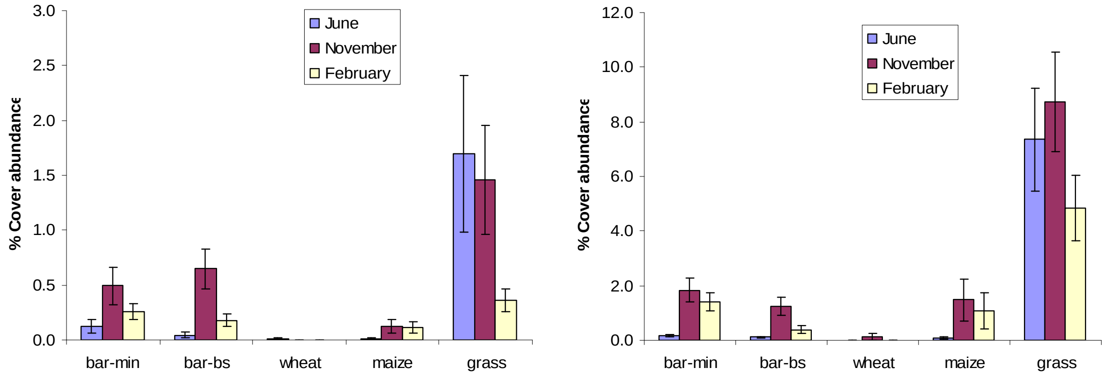

(c) *Veronica persica* (d) *Viola arvensis*

Figure 6. Percentage cover (means ± se) of the four most abundant biennial/perennial forbs according to treatment and month. The treatment x month interaction was not significant for *C. vulgare*, so only the treatment means are presented (treatments with the same letter do not differ significantly from on another).


(a) *Cirsium vulgare*

(b) *Rumex obtusifolius*


(c) *Taraxacum officinale*

(d) *Trifolium repens*

3.3.3 Abundance of reproductive plants. Cover of reproductive plants always varied between treatments and usually between months but not usually between years or according to distance to the field boundary (Table A.4.2; Appendix 4). Reproductive *L. multiflorum* and *L. perenne* was largely restricted to grass fields during June (Fig. 7a & 7b). Reproductive *P. trivialis* was common during June in all treatments except maize (Fig. 7d). In contrast, reproductive *P. annua* was abundant in both barley treatments during winter (particularly during November) but was scarce in all other treatments. During June, reproductive *P. annua* was commonest in wheat and scarce in grass (Fig. 7c).

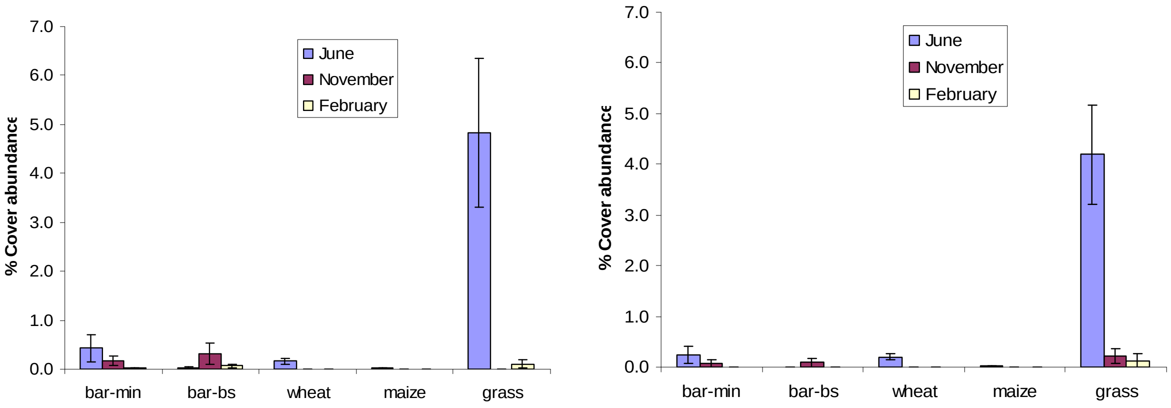
Three of the commonest forbs (*Polygonum persicaria, Stellaria media* and *Viola arvensis)* were all reproductively abundant on barley fields (but scarce on other treatments) during November, with much lower levels of abundance on all treatments during February and June (Fig. 8a, b & d). Reproductive cover of *Veronica persica* was greatest on the barley treatments and lowest on grass (Fig. 8c). Reproductive cover of *Fumaria officinalis* and *Stellaria media was* significantly greater 30m into the crop compared to 2m from the crop edge.

3.3.4 Effects of broad-spectrum herbicide application on the vegetation of barley fields. To investigate the impacts of broad-spectrum herbicide application on the flora of barley crops, we conducted further analyses restricted to the vegetation data from the two barley treatments (Table A.4.3; Appendix 4). There was no evidence of any effect of barley treatment on any of the vegetation measures including general cover scores (Table A.4.3), cover of individual grass and forb species (Table A.4.4; Appendix 4) and the cover of reproductive plants (Table A.4.5; Appendix 4).

There was a significant effect of crop age (Table A.4.3) in which grass and forb cover increased in the second year of the barley treatments. Mean grass cover was 26.0% (± 2.3 se) in the first year and 36.0% (± 2.5 se) in the second year. Mean forb cover was 12.5% (± 1.3 se) in the first year and 15.7% (± 1.3 se) in the second. At the species level (Table A.4.4), there was only one case of a significant barley age effect (*Rumex obtusifolius* was less abundant in the second year), and only two cases of significant barley age by treatment interactions (*Sinapsis arvensis* was more abundant in second year BAR-MIN treatments and less abundant in second year BAR-BS treatments, while an opposite trend was evident for *Poa pratensis*). There was no effect of barley age on the abundance of reproductive plants (Table A.4.5).

Figure 7. Percentage reproductive cover (means ± se) of four common grass species by treatment and month.

(a) *Lolium multiflorum* (b) *Lolium perenne*



(c) *Poa annua* (d) *Poa trivialis*

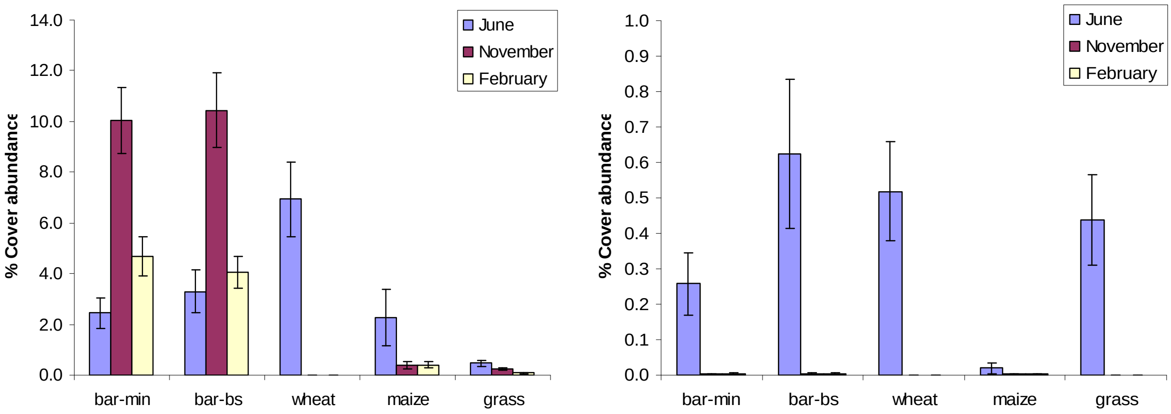
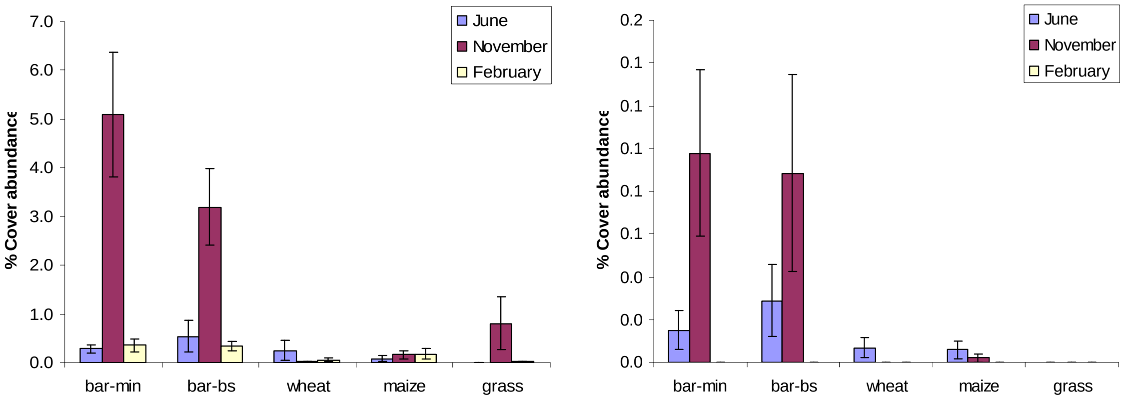
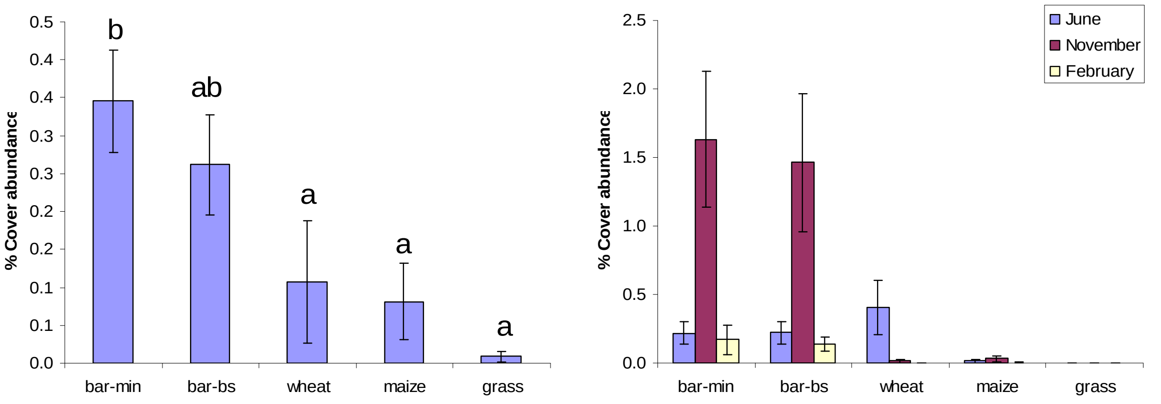


Figure 8. Percentage reproductive cover (means ± se) of four common forb species by treatment and month. The interaction between treatment and month was not significant for *V. persicaria*, so only treatment means are presented. Treatments with the same letter do not differ significantly ($P > 0.05$).

(a) *Polygonum persicaria* (b) *Stellaria media*



(c) *Veronica persica* (d) *Viola arvensis*



Seasonal variation (significant month effect) in the cover of crop, grass, forbs and bare ground (Table A.4.3) are also evident in Fig. 3. Seasonal effects (Table A.4.4) differed between species although there was a tendency for spring-germinating annuals such as *C. album* and *P. persicaria* to be most abundant during June. In contrast, abundance of more generalist species like *S. media* peaked during November.

3.4 Invertebrate assessments.

3.4.1 Sweep netting. The relative abundance of all invertebrate groups varied strongly between treatments (Table A.5.1; Appendix 5). Larval abundance was greatest in cereal crops and lowest in maize and (with the exceptions of Symphyta and Neuroptera) grass (Fig. 9). Abundance of adult invertebrates was generally greatest in grass and cereals and lowest in maize (Figs 10 & 11). Abundance of Elateridae, Curculionoidea and Auchenorrhyncha was significantly higher in grass than in any of the other treatments (Fig. 10). There were no significant differences in the abundance of sweep net invertebrates between the two barley treatments. All significant distance effects (Table A.5.1) reflected a higher invertebrate abundance 2m from the field boundary than 30m into the crop.

Fig. 9. Mean abundance (± se) of (a) Diptera, Symphyta, Neuroptera and (b) other Coleopteran larvae captured in sweep nets (pooled count from 30 sweeps within an area 2m x 15m).Treatments with the same letter within categories do not differ significantly (*P* >0.05).

(a) Diptera, Symphyta and Neuroptera (b) other Coleoptera

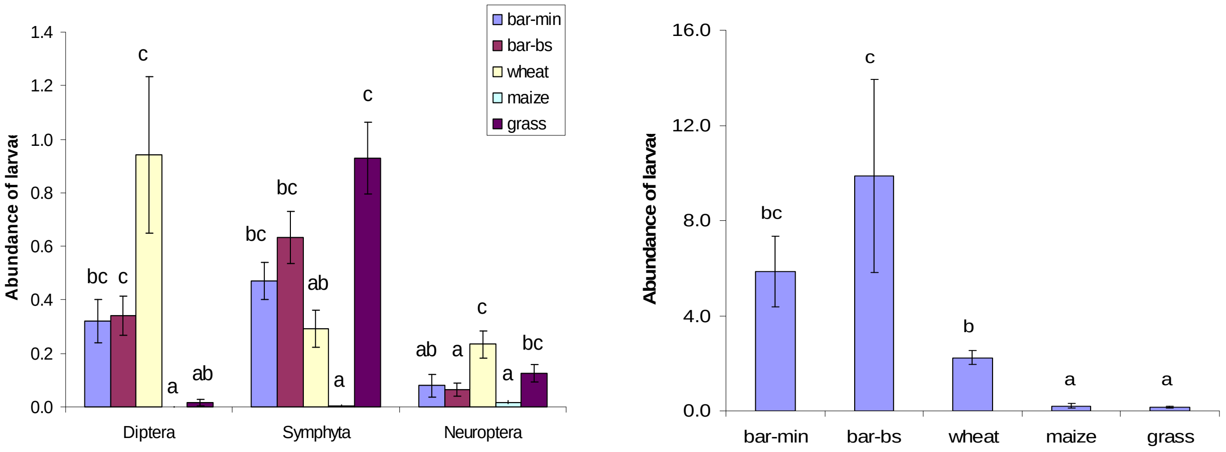


Fig.10. Mean abundance (± se) of adult Staphylinidae, Elateridae, Curculionoidea, Other Coleoptera, Auchenorrhyncha, Hymenoptera and Symphyta captured in sweep nets (pooled count from 30 sweeps within an area 2m x 15m). Treatments with the same letter within each category do not differ significantly, *P*>0.05).

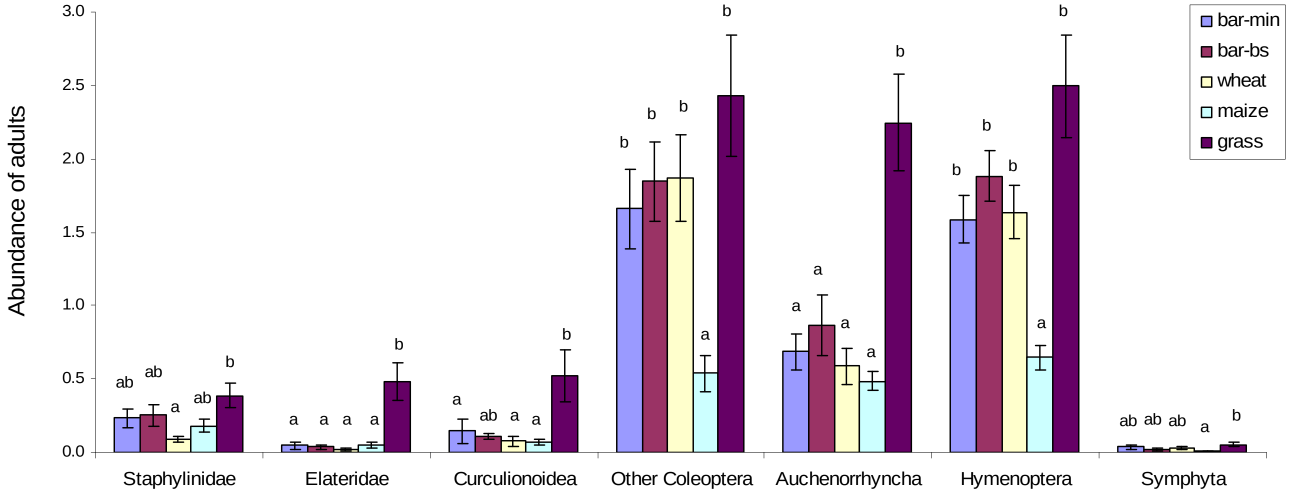
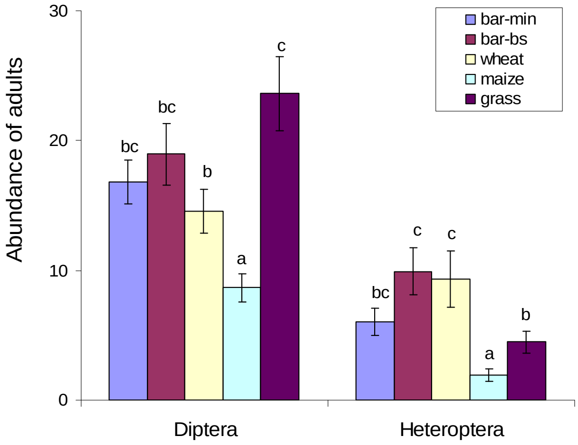


Fig. 11. Mean abundance (± se) of Diptera and Heteroptera adults captured in sweep nets (pooled count from 30 sweeps within an area 2m x 15m). Treatments with the same letter within each category do not differ significantly (P>0.05).



3.4.2 Vortis sampling. The relative abundance of most invertebrate groups sampled using Vortis suction units varied strongly between treatments (Table A.5.2; Appendix 5). Larval abundance was lowest in maize crops and similar in the other four treatments (Fig.12). Some treatment responses differed between the two sampling techniques most notably a tendency for the sweep net to under-sample Dipteran and other Coleopteran larvae on grass fields (Figs. 9 cf. 12). Coccinellidae and Neuroptera larvae were more abundant at 2m from the crop edge, while ‘other’ Coleoptera were more abundant 30m into the crop.

Fig.12. Mean abundance (± se) of (a) Coccinellidae, Diptera, Symphyta, Neuroptera and (b) other Coleopteran larvae captured in Vortis samples (each comprising 15 ten-second sucks within a 2m x 15m area).Letters show treatments that do not differ significantly (*P* > 0.05).

(a) (b)

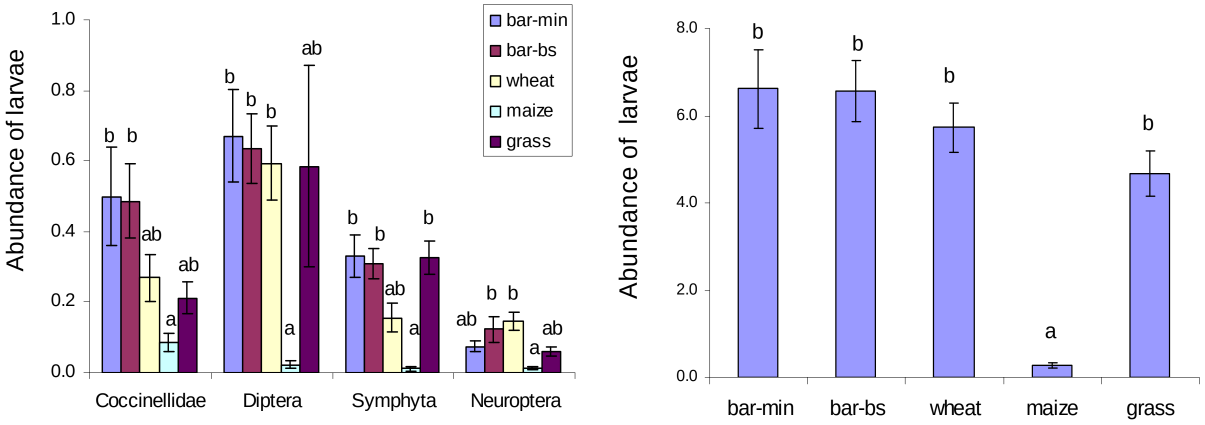
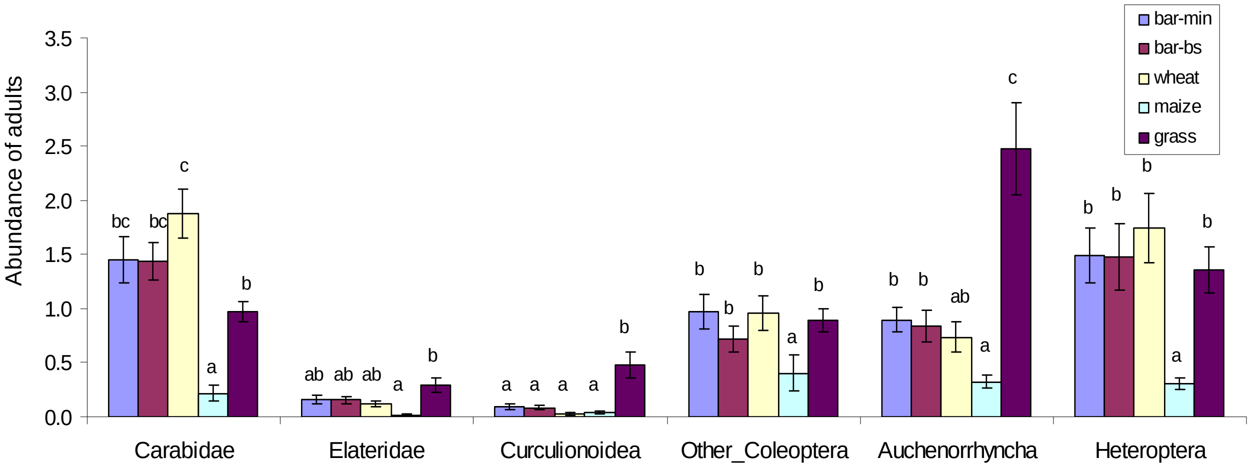
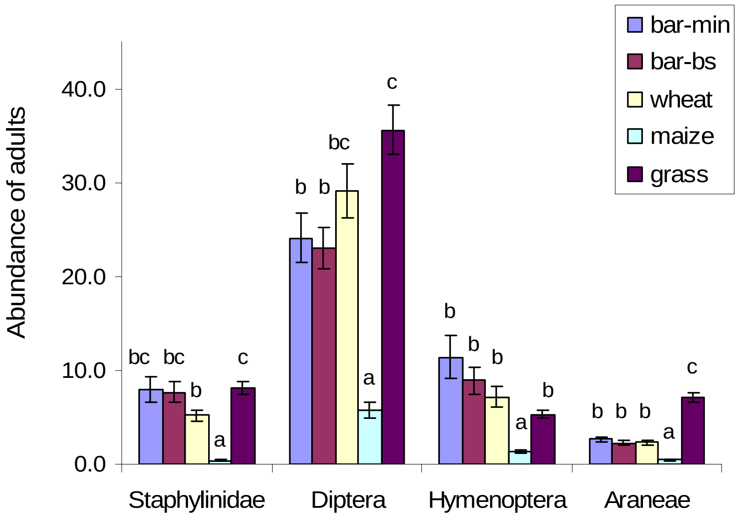


Fig. 13. Mean abundance (± se) of adult Carabidae, Elateridae, Curculionoidea, ‘Other’ Coleoptera, Auchenorrhyncha and Heteroptera captured with the Vortis (each comprising 15 ten-second sucks within a 2m x 15m area).Treatments with the same letter within each category do not differ significantly (*P* > 0.05).



Treatment effects for adult invertebrates were generally similar to those found with sweep netting. Adults of most groups were least abundant in maize and most abundant in grass and/or the various cereals (Fig. 13). There was no evidence that adult abundance differed between the three cereal treatments.

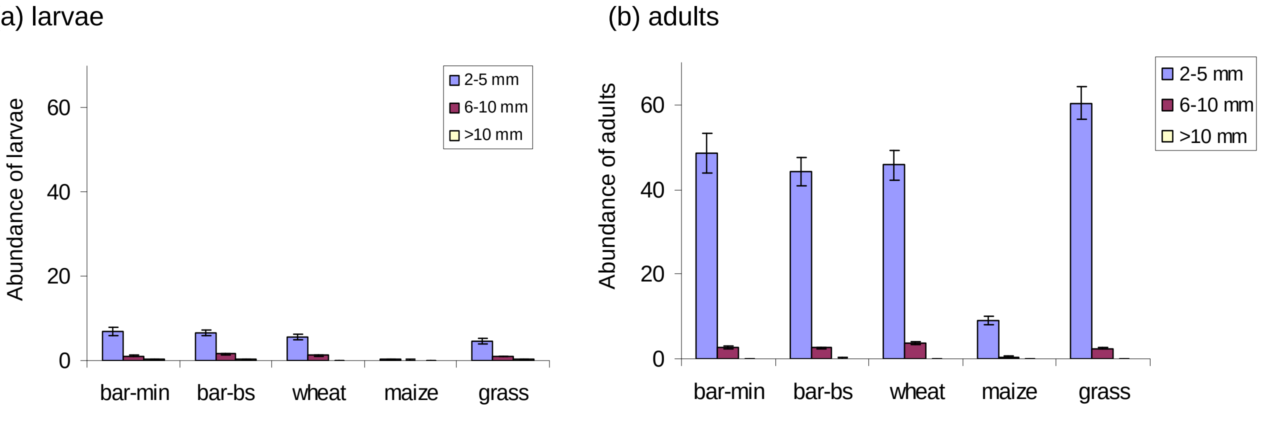
Fig. 14. Mean abundance (± se) of adult Staphylinidae, Diptera, Hymenoptera and Araneae captured in Vortis samples (each comprising 15 ten-second sucks within a 2m x 15m area). Treatments with the same letter within each category do not differ significantly (*P* > 0.05).



Most of the eight significant distance effects (Table A.5.2) reflected a higher abundance of invertebrates 2m from the field boundary, the exceptions being Elateridae and Diptera.

3.4.3 Invertebrate size distribution. The size distribution of the combined larvae and adult samples varied significantly between treatments, with the relative abundance of different size categories also differing between treatments (Table A.5.3; Appendix 5). Most invertebrates were 2-5mm long, with very few longer than 10mm. All invertebrate size categories were least abundant in maize crops, and intermediate-sized invertebrates (6-10mm) were proportionately under-represented in maize crops (Fig. 15). Variation in size distribution patterns across treatments was similar for sweep net and Vortis samples.

Fig.15. Variation in the size distributions of (a) larvae and (b) adult invertebrates captured in Vortis samples (each comprising 15 ten-second sucks within a 2m x 15m area).

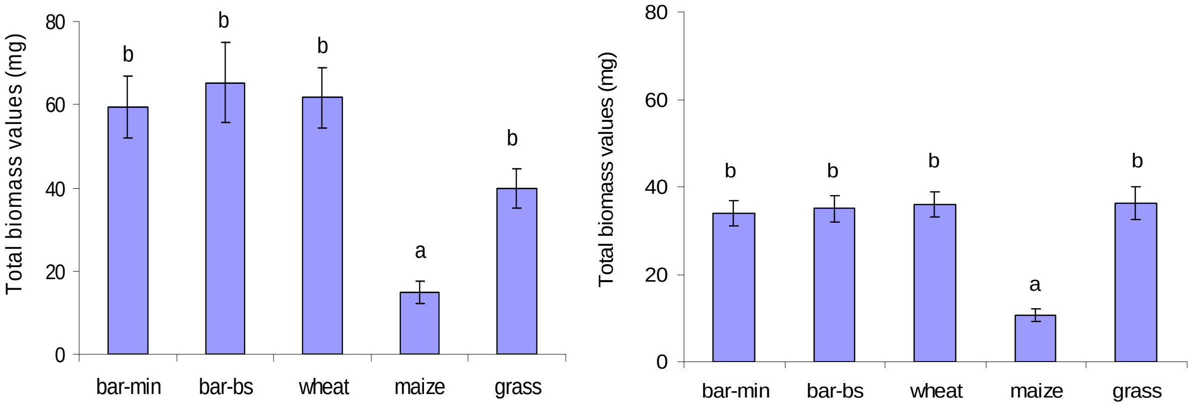

(a) larvae

(b) adults

3.4.3 Invertebrate biomass differed significantly between treatments (sweep net data: $F_{4,63.6} = 22.7$***; Vortis data: $F_{4,59.3} = 25.5$***). In both cases, total biomass was significantly lower in maize than in all other treatments and there were no differences in biomass between the other four treatments (Fig. 16). Invertebrate biomass (as sampled by sweep netting) was higher 2m from the field boundary than 30m into the crop ($F_{1,150} = 38.2$***; mean biomass of 60.0 mg (± 5.3) vs. 34.6 mg (± 2.9) per sample) although the same difference was not evident from the Vortis samples.

3.4.4 Effects of broad-spectrum herbicide application on the invertebrates of barley fields.
There was no evidence from sweep netting or Vortis sampling that invertebrate abundance, size distribution or total biomass differed significantly between the two barley treatments or between first and second summer barley treatments.

Fig 16. Total invertebrate biomass (+/- se) (larvae plus adults) per (a) sweep net and (b) Vortis samples (comprising, respectively, 30 sweeps and 15 ten-second sucks within an area 2m x 15m).Treatments with the same letters do not differ significantly from one another.



(a) sweep nets

(b) Vortis samplers

3.5 Bird usage assessments

3.5.1 Effects of treatment on bird usage during summer. Significant predictors of the intensity of field usage by ten bird groups/species during summer are summarised in Table A.6.1 (Appendix 6). Nuisance variables that influenced summer field usage included timing of the survey (six groups; usage generally peaked early in the morning), field or TWP enclosure (four groups; mixture of positive and negative effects), field area (negative impact on Hirundines) and the number of internal right angles (positive effect on pigeons & doves). Usage of fields by most bird groups differed significantly between summers (7 out of 10 groups), treatments (9 out of 10 groups), and between early and late halves of the summer (Table A.6.1). The pattern of usage of different treatments also differed between summers (6 out of 10 groups) and between the early/late parts of the summer (Table A.6.1). Variation in the usage of the different treatments (averaged across years) is summarised in Fig. 17.

Granivores, buntings, insectivores and gamebirds made little use of grass during summer, while all three cereals were preferred by granivores, buntings, skylarks and gamebirds (Fig. 17). Usage of cereal crops increased markedly through the summer for granivores, buntings and Hirundines but declined for thrushes, skylarks and insectivores (Fig. 17), possibly reflecting increased availability of ripening grain and small (flying) insects, and declining accessibility due to increases in crop height and density respectively. Maize fields were used by thrushes, Corvids, pigeons & doves and insectivores although usage declined later in the summer. Usage of grass by Hirundines, skylarks, Corvids and pigeons & doves increased through the summer. Lapwings were most frequently observed on maize and barley fields (Fig. 17j) where most observations were associated with nesting. The few observations of Lapwings on grass and wheat were mostly associated with feeding or loafing.

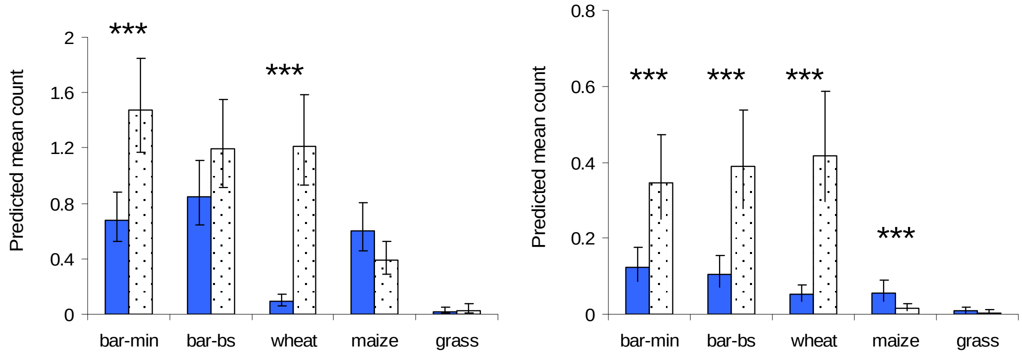
3.5.2 Effects of treatment on bird usage during winter. Significant predictors of the frequency of field usage by eight bird groups/species during winter are summarised in Table A.6.2 (Appendix 6). Nuisance variables that influenced winter field usage included field or TWP area (three groups, all positive) and field enclosure (two groups, both negative). Usage of fields by most bird groups was similar across winters (6 out of 8 groups) and between early and late winter (5 out of 8 groups) but differed significantly between treatments (6 out of 8 groups; Table A.6.2). The pattern of usage of different treatments was generally similar across winters (5 out of 8 groups) but differed significantly between early and late winter (5 out of 8 groups; Table A.6.2). Variation in the usage of the different treatments (averaged across years) is summarised in Fig. 18.

Patterns of field usage in winter fell into two general groupings exhibiting opposing patterns of field usage. Granivores, buntings, skylark and meadow pipit showed a strong and similar preference for the two winter barley stubble treatments (Fig. 18). Skylark usage of barley increased markedly through the winter. The red list priorities skylark and bunting made little use of newly sown wheat or maize stubbles, and almost no use of grass (Fig. 18). Granivores (mainly tree sparrows and chaffinches during early winter) and meadow pipits made significantly more use of maize than wheat or grass fields. A second grouping comprising thrushes, Corvids, insectivores and pigeons & doves made greater usage of maize, wheat and (for thrushes and Corvids), grass, and significantly less usage of barley fields (Fig. 18). Usage of grass by thrushes and insectivores (and skylarks) increased through the winter, while usage of maize by granivores and Corvids declined. Usage of wheat by skylarks and meadow pipits declined from a low level in early winter to a very low level in late winter (Fig. 18).

Fig. 17. Variation in the intensity of usage of treatment fields during early (filled blue) and late (speckled) summer (averaged across years). Presented data are predicted mean counts (across sites, visits and years) after allowing for field-specific nuisance variables (see 2.5 Data analysis). Error bars are standard errors. Early-late effects could not be estimated from the lapwing data, so simple treatment effects are presented (treatments labelled with the same letters do not differ significantly from one another). Statistical significance (****P*<0.005, ***P*<0.01, **P*<0.05, (*)*P*<0.1, ns *P*>0.1) is indicated in sub-headings for 'treatment' / 'treatment' x 'early-late' effects respectively, and on figures for early-late effects.

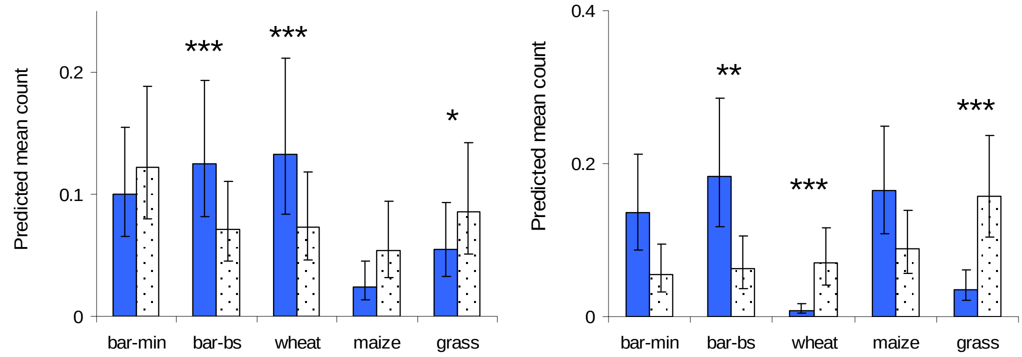
(a) Granivores***/***

(b) Buntings*** /***



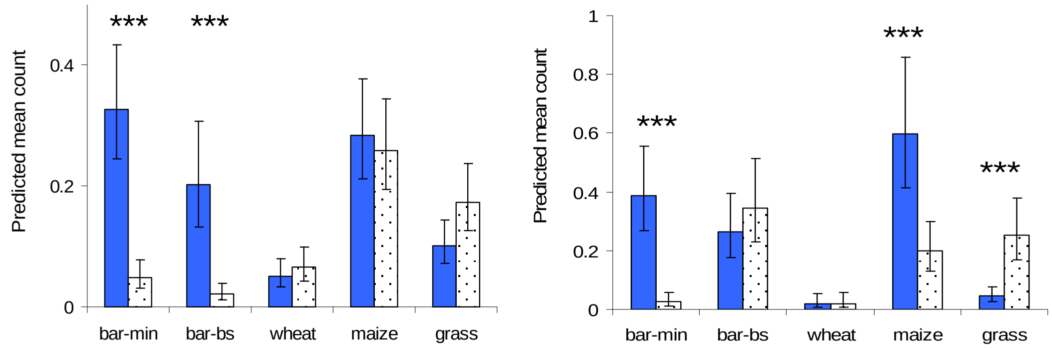
(c) Skylark ns/***

(d) Pigeons/Doves (*)/***



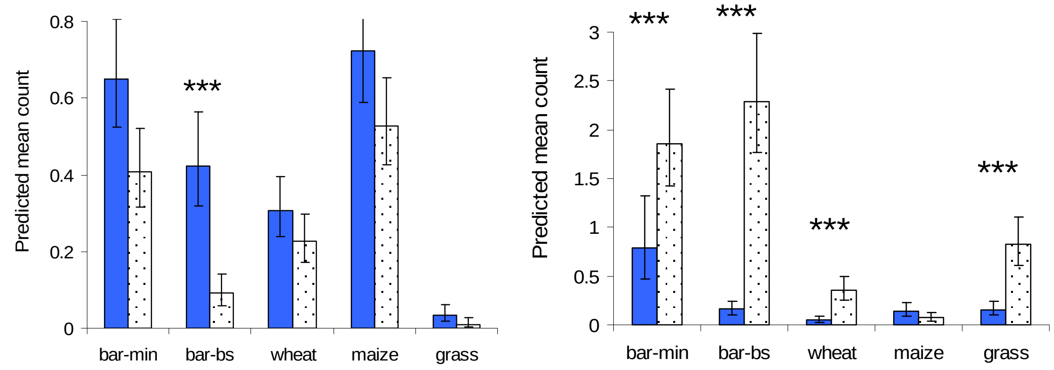
(e) Thrushes***/***

(f) Corvids ***/***



(g) Insectivores ***/(*)

(h) Hirundines ***/***



(Fig. 17. continued overleaf ….)

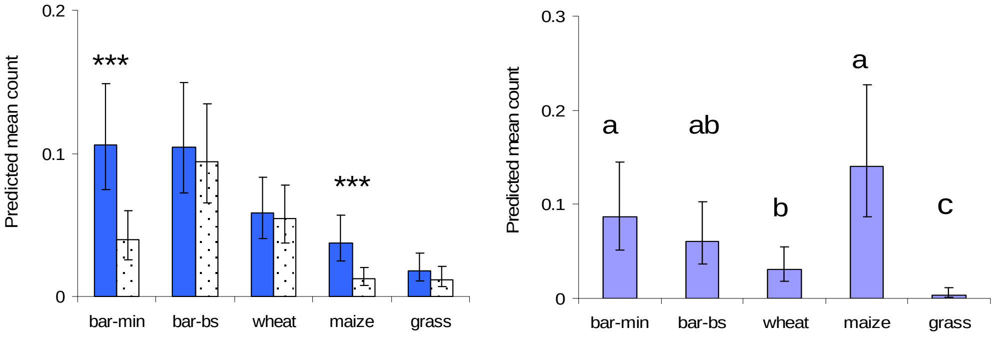
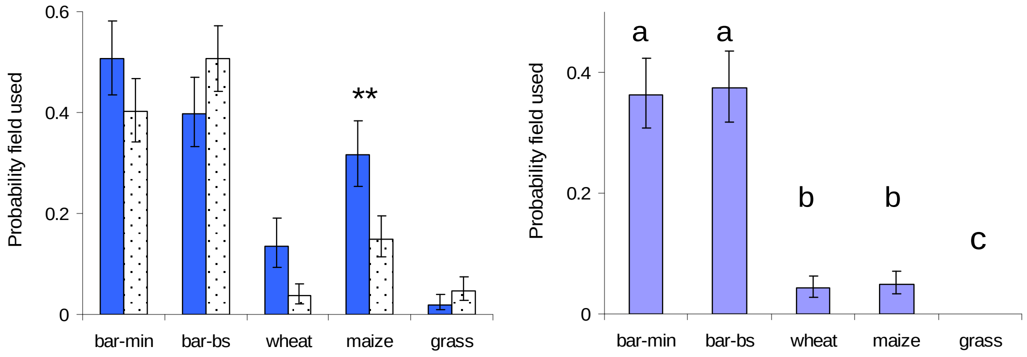

(i) Gamebirds ***/(*)
(j) Lapwing ***

Fig. 18. Variation in the probability of usage of treatment fields during early (filled blue) and late (speckled) winter (averaged across years). Error bars are standard errors. Where early-late effects were not significant, simple treatment effects are presented (treatments labelled with the same letters do not differ significantly from one another). Statistical significance (***P<0.005, **P<0.01, *P<0.05, (*)P<0.1, ns P>0.1) is indicated in sub-headings for ‘treatment’ / ‘treatment’ x ’early-late’ effects respectively, and on figures for early-late effects.

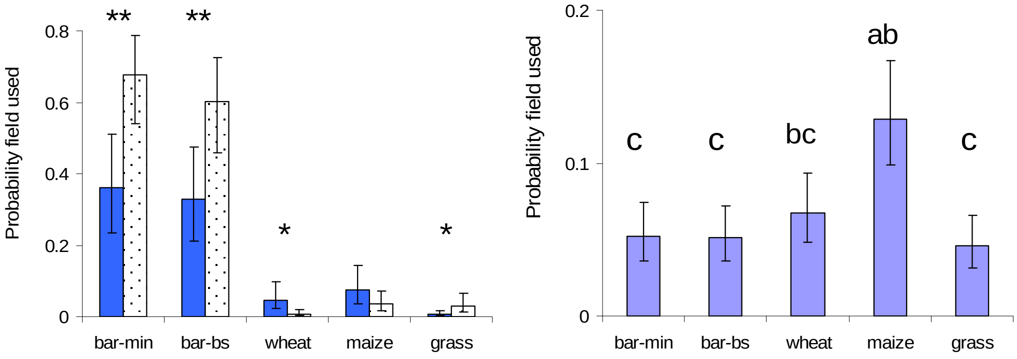
(a) Granivores***/***

(b) Buntings*** /ns



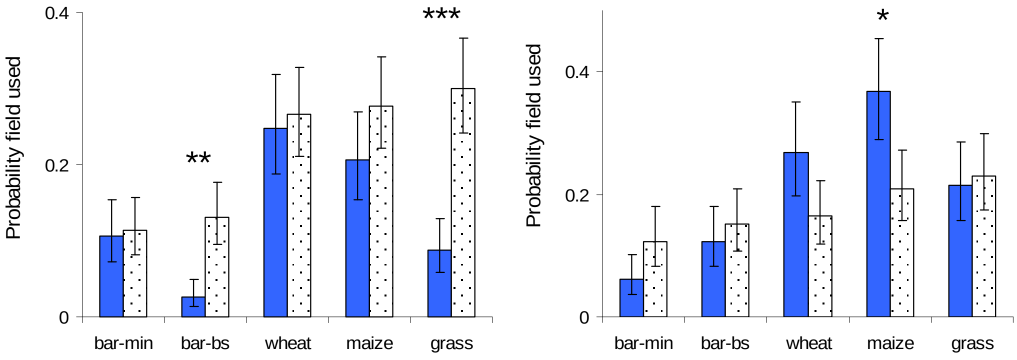
(c) Skylark ***/***

(d) Pigeons/Doves (*)/ns

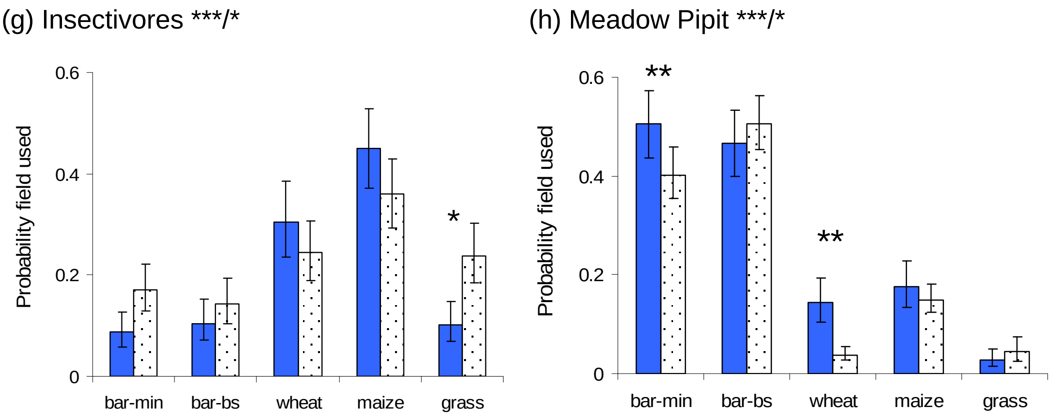


(e) Thrushes***/*

(f) Corvids (*)/(*)



(Fig. 18. continued overleaf ….)


(g) Insectivores ***/*

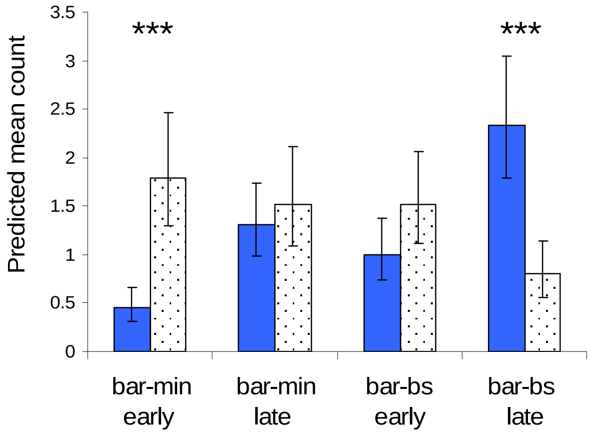
(h) Meadow Pipit ***/*

3.5.3 Effects of broad-spectrum herbicide application on the usage of barley fields by birds.

There was little evidence that the application of broad-spectrum herbicide affected the usage of barley fields during summer or winter. None of the eight bird groups showed differential usage of the two barley treatments during winter, while only two groups showed differential usage during summer (insectivores made greater usage of BAR-MIN treatments (*P*=0.0053) while Corvids made greater usage of BAR-BS plots (*P*=0.03), Fig. 17).

There was little evidence of differential usage of first and second year barley treatments during summer or winter (Table A.6.3; Appendix 6). Buntings showed reduced usage of second year winter stubbles and Corvids showed enhanced usage of second winter stubbles. Granivorous passerines showed significantly enhanced usage of second (early) summer BAR-MIN crops and reduced usage of second (late) summer BAR-BS crops (Table A.6.3, Fig. 19). There was also a weak tendency (*P*=0.095) for buntings to make greater usage of second year BAR-MIN crops, and less usage of second year BAR-BS crops, during summer. Corvids showed a significant reduction in their late summer usage of BAR-BS crops although there was no overall crop age effect (Table A.6.3).

Fig. 19. Variation in the intensity of usage of early and late summer barley treatments by granivores during the first (filled blue) and second (filled speckled) years of production. Error bars are standard errors. Statistical significance (****P*<0.005) is indicated on figures for crop age effects.

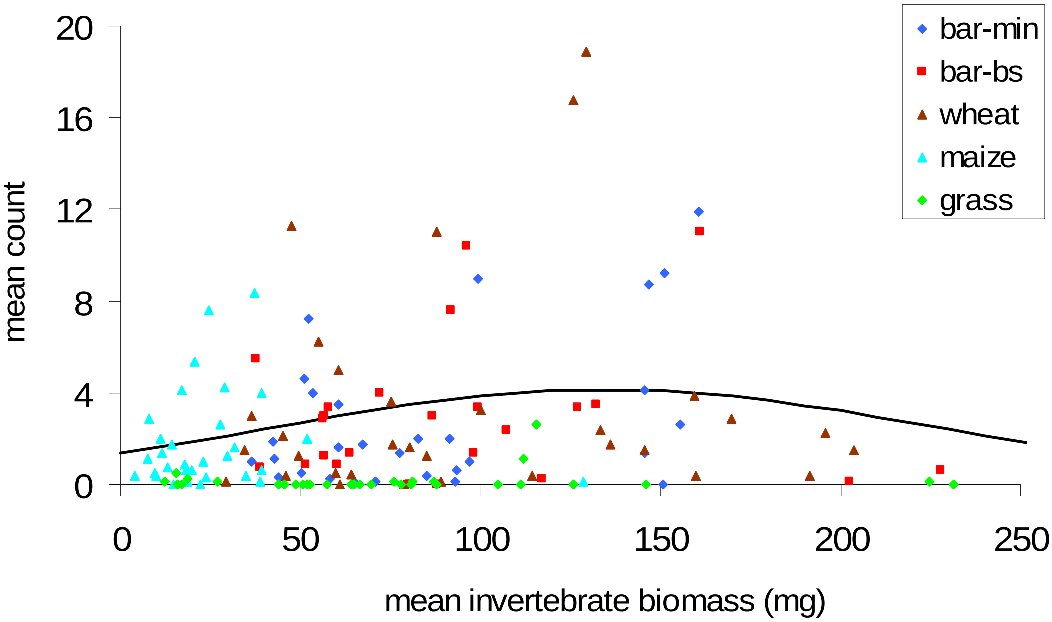


3.5.4 Effects of vegetation cover and invertebrate biomass on field usage.

Strong correlations (across fields) between several of the vegetation cover scores limited our ability to distinguish the effects of different cover components on bird field usage. Total forb cover was strongly correlated with the cover of reproductively active forbs (r=0.71 in summer and 0.65 in winter) and total *P. annua* cover was strongly correlated the cover of reproductively active *P. annua* (r=0.96 in summer and 0.90 in winter). The cover of reproductively active grass was also strongly correlated with the cover of reproductively active *P. annua* (r=0.59 in summer and 0.99 in winter). June invertebrate biomass was not strongly correlated with any of the June vegetation scores (r=0.30 with cover of reproductively active grasses was the strongest).

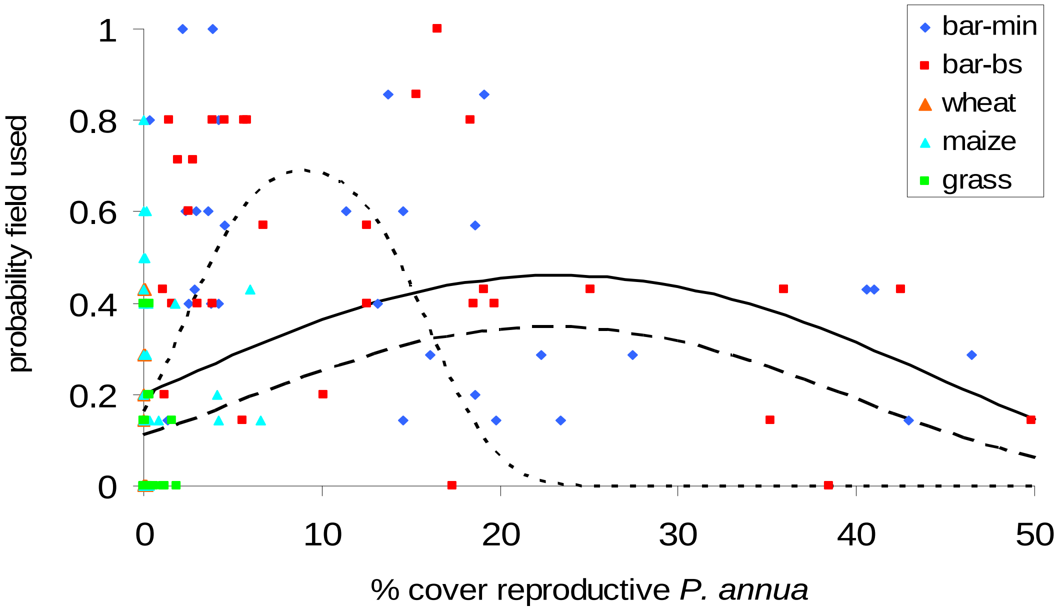
During summer, several bird groups (skylark, thrushes, insectivores, pigeons & doves, gamebirds and lapwing) showed a preference for fields with intermediate levels of forb cover especially reproductively active forb cover (Table A.6.4; Appendix 6). All of these relationships involved increasing field usage as forb cover increased up to some optimal cover value and declining usage at higher levels of cover. Granivores, Buntings, Hirundines and Corvids all showed curvilinear relationships between summer field usage and invertebrate biomass (Table A.6.4, Fig. 20). The decline in the usage of the relatively small number of fields with the largest invertebrate biomass was significant even after allowing for the negative influence of grass cover summer field usage. This suggests that prey availability was limited by some other factor such as crop height and density. Grass fields tended to be little used by granivores even when they supported a relatively high invertebrate biomass, while maize fields received greater usage despite supporting lower invertebrate biomass (Fig. 20).

Fig. 20. Relationship between summer field usage by granivores (mean count across visits) and invertebrate biomass (mean Vortis and sweep net measures averaged between 2m and 30m from the boundary) in June. Each point represents a single field during a single year. The line shows the predicted relationship for early morning bird surveys and a mean grass cover score (both of which influenced summer field usage by granivores; see Tables A.6.1 & A.6.4). The slightly high level of the line reflects higher counts during early morning surveys.



Cover of reproductively active *P. annua* was the strongest predictor of winter field usage by granivores, buntings, skylarks and meadow pipits (Table A.6.4). As in summer, the relationship was strongly curvilinear with field usage increasing up to some optimal cover score beyond which usage declined (Fig. 21). Reduced prey accessibility offers a possible explanation for the observed reduction in the usage of fields with relatively high grass cover (Fig. 21), although in the case of skylark reduced usage of fields with high cover of reproductively active *P. annua* was evident after allowing for a negative influence of high grass cover on usage (Table A.6.4). The form of the curvilinear relationship differed markedly between years with a lower optimal cover score during the second winter of the study (ca. 10% cover of *P. annua* compared to ca. 25% in the other two winters; Fig. 21). Overall usage of study fields was highest during the first winter of the study and lowest during the third winter. Granivores and buntings also made greater usage of winter fields with a higher cover of reproductively active forbs (Table A.6.4). The inverted curvilinear relationships between field usage by thrushes and insectivores and various cover measures reflected relatively heavy usage of crops with low cover scores (i.e. wheat, maize and grass) coupled with zero usage of several barley stubbles having intermediate levels of cover.

Fig. 21. Relationship between the observed probability of fields being used by granivorous passerines during winter and the cover of reproductively active *P. annua* (averaged between 2m & 30m from the field boundary and between November & February). Each point represents a single field in a single winter. Lines show the form of the predicted relationship during each winter (filled line 2004/5, short dashes 2005/6, long dashes 2006/7).



4. Discussion.

4.1 Biodiversity benefits of different silages. Several clear findings emerge from these studies regarding the relative utility of the different silage crops for foraging farmland birds and their food resources.

Both barley treatments were heavily utilised by a wide range of priority farmland birds particularly during winter but also during summer (Figs. 17 & 18). The important seed-eating guild (‘granivores’), buntings, skylark and meadow pipit all showed a strong preference for winter barley stubbles and this probably reflects the relative abundance of reproductively active *P. annua* and forbs (Figs. 4, 5 & 21). Usage of barley stubbles by seed-eating species remained high during the second half of the winter (skylark usage increased) despite a marked decline in the abundance and reproductive activity of most forbs by February (Figs 3, 5, 6 & 8). This marked decline in seed abundance between November and February is illustrated for two key bird food species (*P. persicaria* & *S. media*) in Fig. 8. *Poa annua* is one of the few common plants to remain reproductively active during late winter (Fig. 7) and may be particularly important for seed-eating farmland birds at this time of probable food shortage. Summer barley treatments were heavily utilised by mixed diet granivores and skylarks plus gamebirds, insectivores, Hirundines and to a lesser extent nesting lapwings. The mixed diet granivores (buntings, finches, sparrows) will have been gathering invertebrates and ripening grain as well as seeds of spring-germinating weeds such as *C. album* (Wilson *et al*. 1999). The marked increase in the usage of all cereal treatments by granivores (especially buntings) and of barley by Hirundines during summer (Fig. 17) probably reflects increases therein in the abundance of weed seed, ripening grain and invertebrates like Diptera (Holland *et al*. 2002). Thrushes used barley treatments early in the growing season when access to the ground (for soil invertebrates) was unrestricted by crop structure, but usage subsequently declined as the barley crop matured (Fig. 17e). The only bird groups to make relatively little usage of barley treatments were thrushes and Corvids both of which have a generally favourable conservation status.

A surprising but clear conclusion from this study was the modest biodiversity benefits of restricting broad-spectrum herbicide application to spring barley. Despite some small non-significant differences in winter forb cover between BAR-MIN and BAR-BS treatments (e.g. Figs. 3c, 6b & Fig. 8a) there were no differences in crop or grass cover, bare ground or invertebrate abundance or biomass between the two barley treatments. The only notable difference in bird activity involved higher usage of BAR-MIN by insectivores during summer, and there were no differences in barley usage during winter. The apparent lack of impact of broad-spectrum herbicide application on forb cover even in June (Fig. 3c; i.e. a few weeks after application) is surprising and might reflect late spraying (the products used are all contact herbicides that are most effective on young weed seedlings) or in some cases dilute application rates. Several of the farmers were not keen to apply broad-spectrum herbicide and had to be reminded and encouraged to do so (hence several delayed application dates). The lack of differences in forb cover between barley treatments in November and February are less surprising given the ability of many common arable weeds (e.g. *S. media* and *V. arvensis*) to germinate throughout most of the year. There was also little evidence of significant biodiversity benefits of growing spring barley for a second year in succession. Although there was a small increase in mean forb cover (from 12.5% in the first year to 15.7% in the second year) there was no systematic increase in bird usage in the second year (winter bunting usage fell possibly in response to a larger increase in grass cover).

Growing wheat was strongly avoided by most conservation priority species during winter. The main species to utilise wheat during winter were soil-invertebrate feeders requiring access to the ground (fig. 3d) such as thrushes, Corvids and insectivores (Fig. 18). Autumn cultivation followed by winter or spring herbicide application were the probable causes of the relatively low forb abundance on wheat fields during winter and summer (Fig. 3c). During summer, wheat fields were generally less attractive to foraging birds than barley fields but more attractive than grass (and in some cases maize) especially during late summer (Fig. 17) presumably reflecting a relative abundance of reproductively active plants such as *P. annua* (Fig. 7c) and *V. arvensis* (Fig. 8d) at that time and a general increase in grain and invertebrate resources. The markedly higher use of barley rather than wheat by aerial feeding Hirundines (mainly swallows) during summer presumably reflected a much higher abundance of flying Diptera and aphids that was not detected by our invertebrate sampling. Most wheat fields in this study received insecticide application (mainly aphicides) while most barley fields (29 of the 32 crops) did not.

Maize is vulnerable to competition from broad-leaved weeds during establishment and is routinely treated with highly effective herbicides like atrazine or more recently products like ‘Stomp’. This probably accounts for the lack of forb cover (and reproductively active forbs and grasses) on maize fields especially during winter (Figs. 3, 5, 7 & 8). In marked contrast to barley stubbles, forb abundance on maize fields was lower in November and February than in June suggesting low post-harvest establishment on maize. The relatively late harvesting of maize may limit opportunities for autumn germination and emergence of forbs. Lack of seed resources probably explains the relatively low usage of maize stubbles during winter by granivores, buntings, skylarks and meadow pipits (Fig. 18) while modest summer resources of species like *C. album* and seeding *P. annua* (Figs. 5a & 7c) might explain modest summer usage of maize by some granivorous birds (Fig. 17a). Lack of weed flora may partly explain the significantly lower abundance and biomass of invertebrates on maize during summer (Fig. 16) although the timing of sampling (June) may have been too early in the growing season for invertebrate communities to develop.

Relatively heavy usage of maize by small insectivores during summer and winter (Figs. 17 & 18) suggests that invertebrate densities may have been higher at other times of year. Several ground-feeding insectivorous bird groups (like thrushes, Corvids and small insectivores) made relatively intensive usage of maize stubbles (Fig. 18) and growing maize during spring and summer. For these species, good access to the ground and soil (as a consequence of spring ploughing and relatively large areas of bare ground) presumably offsets the generally reduced abundance of invertebrates at least during summer. Thrushes might also be attracted to maize crops by the presence of fruiting *Solanum nigrum*. A late summer reduction in maize usage (statistically significant for buntings, Corvids and gamebirds) was probably a consequence of reduced accessibility caused by the growing crop.

Relatively heavy usage of maize stubbles during early winter by tree sparrows, chaffinches (both 'Graniovores'), rooks and jackdaws probably reflects the post-harvest availability of cracked maize grain which is either depleted by predators or rots as the winter progresses. Low late winter usage of maize stubbles by most seed-eating birds suggests this habitat has little value as a foraging habitat during this period of potential food shortage, although there was modest usage of the weedier maize stubbles by buntings during April before fields were ploughed (Fig. 17b). The preference of lapwings for maize fields (Fig. 17j) supports the findings of previous studies that have shown high rates of nesting rates on maize fields followed by high nest failure rates caused by farming operations or predation (Simpkin 2002, Sheldon 2002). The timing of maize usage (following cultivation in early May) suggests these may be second nesting attempts following failures on other fields. There is a risk that maize acts as a sink habitat for lapwings (high densities and low productivity) which have declined markedly in many pastoral dominated regions of Britain (Wilson *et al*. 2001).

Grassland was little used by most farmland birds (particularly conservation priority species and groups) during summer or winter. The greatest usage of grass was made by soil-invertebrate-feeding species (mainly thrushes and Corvids) during winter and to a lesser extent during summer (Figs. 17 & 18). Grassland is a relatively rich source of important soil invertebrates including earthworms and leatherjackets (Tucker 1992) that is readily exploited by soil-invertebrate feeding birds as long as access to the soil is not hindered by tall and/or dense grass swards (Whittingham & Evans 2004, Buckingham *et al*. 2006). The marked late-winter increase in grass usage by thrushes (Fig. 18e) may reflect increased availability of earthworms at that time (as found by Tucker 1992). Moderate usage of grass especially during late summer was evident for skylarks (which commonly nest in grass silage), pigeons & doves, Corvids and Hirundines (Fig. 17). Late summer foraging in or over grass silage may have been promoted by second silage cuts (promoting access to food resources), invertebrate responses to slurry application and aftermath grazing (Buckingham *et al.* 2006). The strong avoidance of grass during summer and winter by most seed-eating birds probably reflects the severe lack of forbs (Figs 5 & 8) and reproductively active grasses especially during winter (Fig. 7). Resource provision was mainly restricted to *L. multiflorum*, *L. perenne*, *T. officinale* and *T. repens*. Abundant seed from ryegrass (*Lolium* spp.) can be an attractive feeding resource for buntings (Buckingham & Peach 2006) but modern grassland management severely limits the flowering and seeding of agricultural grassland. The strong avoidance of grassland during summer by small insectivorous birds and mixed-diet granivores is contrary to the moderately high densities and biomass of a range of suitable invertebrate prey (Figs. 16 & 20) and may reflect limited accessibility of invertebrate prey in the tall, dense silage swards. Grass fields supported a greater abundance of adult Elateridae, Curculionoidea, Auchenorrhyncha, Araneae and Diptera which probably reflects the abundant resources for both foliage and root herbivores, and the lack of soil cultivation providing a more stable habitat for the completion of life cycles. Annual cultivation in the cereal treatments also had the potential to limit the abundance of some of the key invertebrate groups as it exposes them to predation, desiccation and physical damage or burial at a depth from which emergence is impossible (Holland & Reynolds, 2003).

To summarise the key treatment preferences of different bird groups:

1. Granivorous passerines (generally a high conservation priority group) showed strong a strong preference for barley stubbles during winter and strong avoidance of grass and wheat (use of maize stubbles was intermediate). This was especially true of red-list skylarks, yellowhammers and reed buntings, but also of sparrows, finches and meadow pipits. Usage of fields during winter was positively related to the abundance of reproductively active *P. annua* (although high levels of grass cover was associated with reduced usage presumably as a consequence of reduced accessibility) and the abundance of reproductively active forbs. Usage of barley stubbles was maintained during late winter (increased in the case of skylark) despite marked reductions in the abundance and reproductive activity of forbs and *P. annua* suggesting that late winter may be a period of potential food shortage for granivorous farmland birds.

The same guild (plus gamebirds) preferred barley and wheat during summer, field usage declining with grass cover and increasing with invertebrate biomass. For granivores and buntings this preference for cereals increased during late summer presumably as a consequence of increasing invertebrate biomass and grain availability, while for skylarks late summer usage of wheat and barley (at least that treated with broad-spectrum herbicide) declined presumably as a consequence of increasing crop height and density rendering the crop less suitable as a nesting habitat (Wilson *et a*l 1997, Donald *et al.* 2002). However, skylark usage of BAR-MIN treatments was sustained during late summer (Fig. 17).

2. Thrushes and Corvids (generally lower conservation priority groups) preferred wheat, maize and grass during winter, and maize, barley and grass during summer. Access to the ground for these soil-invertebrate feeding birds is limited in tall dense vegetation. The late winter increase in thrush usage of all treatments may partly reflect depletion of fruit resources in trees and hedges, possibly combined with an increase in the availability of soil invertebrates.

3. Small ground-feeding insectivores preferred maize during summer and winter (despite relatively low invertebrate numbers and biomass measured in June) and barley treated with narrow spectrum herbicide. Aerial insectivores (mainly swallows) strongly preferred barley (and to a lesser extent grass) during late summer presumably reflecting a late summer increase in adult Diptera and aphids.

4. Lapwings (a high priority ground-nesting species) preferred maize and barley and avoided wheat and grass during the summer. Previous studies have found high failure rates of lapwings nesting on maize fields and nesting success was probably higher on spring-sown barley (Sheldon 2002).

5. There was little evidence that avoiding the use of broad-spectrum herbicide, or growing barley for two years in succession, promoted the attractiveness of barley fields to birds or the abundance of food resources therein.

6. The greater abundance of many seed-bearing plants close to the field boundary will probably benefit the majority of granivorous birds which tend to forage within 10m of field boundaries (ref or appendix). The higher densities of weeds close to field boundaries is probably a consequence of reduced agricultural inputs at headlands coupled with greater opportunities for propagule dispersal from neighbouring uncropped areas. Two forbs important in the diets of farmland birds (*S media* & *F. officinalis*) were more abundant 30m into the field than on the field edge, where they would be more accessible to boundary-avoiding birds like skylark and meadow pipit. Similar effects of distance to field boundary on patterns of weed abundance have been reported by Marshall (1989).

7. Invertebrate biomass promoted summer field usage by granivores, buntings, Hirundines and Corvids. Forb cover promoted summer field usage by skylarks and insectivores, while cover of reproductively active forbs promoted summer field usage by thrushes, pigeons & doves, gamebirds and lapwings. Cover of reproductively active *P. annua* promoted winter field usage by granivores, buntings, skylarks and meadow pipits.

4.2 Yield, feed quality and costs of different silages. The winter wheat wholecrop silage had three important agronomic advantages over the barley wholecrop:

1. overall yield was substantially higher (41% higher than BAR-BS and 58% higher than BAR-MIN);
2. variability in yield over the three years was substantially lower (the difference between the highest and lowest annual mean yields was just 7% for WHEAT, compared to 26% for BAR-BS and 35% for BAR-MIN, Table 1);
3. silage quality was higher (4.3% higher starch content, 2.1% higher D-value, 3.1% higher ME) although BAR-BS silage had slightly higher protein content (0.8%) than wheat silage.

Most of the other differences in silage quality between the wheat and barley treatments were small in magnitude and unlikely to have major impacts on animal performance. Application of broad-spectrum herbicide on spring barley had a modest but statistically significant impact on overall yield (a mean increase in yield of 1.15 t DM/ha or 12.4%) but no impact on feed quality.

Tables 4 and 5 extend our comparison of silage yield, costs and feed quality to grass, maize and various wholecrop cereal options. Overall yield was substantially higher for wholecrop wheat (but not barley) than would be expected for grass or maize (Table 4). Production costs (£/t DM) are lowest for wholecrop wheat and maize, intermediate for spring barley and highest for grass silage (Table 4). The lower variable costs of spring barley are more than offset by the much lower yields making winter wheat a cheaper silage to produce (£50.3/tDM cf. £57.6 t/DM = 15% lower costs). However, if spring barley is grown for wholecrop as part of an Entry Level Scheme (ELS) agreement (i.e. 230 ELS points/ha for a maximum of 5ha which requires no use of broad-spectrum herbicide and following stubbles to be left in situ overwinter; Defra 2007) then the effective costs to the farmer are much lower than those for producing winter wheat (£36.1/tDM; Table 4). Winter wheat wholecrop is also eligible for ELS points but we did not consider in this study the reduced herbicide management required under ELS rules. Assuming a similar reduction in wheat yield as a consequence of not using broad-spectrum herbicide as observed in this study for barley (i.e. 8.8%), costs of production might increase to approximately £51.2 per tDM which with ELS payments would fall to approximately £33.4/tDM. If wheat yield fell by 4.5% (the average observed reduction in grain production over three years and three sites in the recent SAFFIE study, Jones *et al*. 2007), then production costs might fall to approximately £48.9/tDM and to £31.9/tDM including ELS payments. Thus, with ELS payments, the costs (per tDM) of growing wholecrop cereals are approximately 45% those of growing grass silage (42% for wheat, 47% for spring barley) and approximately 65% those of growing maize (61% for wheat, 69% for barley). The ELS wholecrop silage option requires farmers to leave a stubble through the following winter and farmers are therefore constrained to growing a spring-sown crop during the following growing season.

Table 4. Comparative production costs of different silage crops. Costs are taken mainly from Nix (2007) and Beaton *et al*. (2007). Yield estimates are from Nix (2007) and this study.

Silage Crop		**Grass**	**Maize**	**Winter Wheat**	**Winter Wheat**	**Spring Barley**	**Spring Barley**
Management/treatment		Two cuts *		Fermented	Urea	BS	MIN
Variable costs (£/ha)							
	Seed	12	121	47	47	52	52
	Fertilizer	208	60	130	130	69	69
	Sprays	11	37	126	126	72	35
	Lime	15	15	15	15	15	15
	Additives	60	50	33	92	33	33
Contractor costs							
	Establishment	46	83	85	85	85	85
	Harvesting	300	139	150	165	150	150
Effleunt absorbent ***		76	0	0	0	0	0
Rent		123	123	123	123	123	123
Total costs (£/ha)		**851**	**628**	**709**	**783**	**599**	**562**
Yield (t DM/ha) **		11.1	12.0	14.1	18.3†	10.4	9.2
Costs (£/t DM)		**76.7**	**52.3**	**50.3**	**42.8**	**57.6**	**61.1**
Costs incl. ELS (£/tDM)							**36.1**

* Assuming two successive cuts, and five year leys.

** Yield of wholecrop silage is based on the values obtained in this study. Values for grass and maize taken from Nix (2007).

*** £2/t @ 38t silage/ha (Beaton *et al*. 2007)

† The urea-based wheat yield estimate is based on only four crops grown as part of this study.

The main nutritional advantages to the farmer of substituting some of his grass silage feed with CBWCS are substantially increased dry matter intake (CBWCS are very palatable to dairy cows) and a higher energy intake associated with the much higher starch levels (Table 4; Heron 1996). However, there is little evidence that substitution of grass with CBWCS increases milk yields although there is evidence of increased milk protein (Phipps *et al*. 1995). In contrast, substituting grass silage with maize silage (which has similarly high starch content as CBWCS) increased milk yield, protein and fat content (Phipps *et al.* 1995). This differential impact on milk yield is probably because of the lower D-value and metabolisable energy of CBWCS compared to grass and maize silage. Most of these studies have considered either urea-preserved or untreated fermented wholecrop, and one recent study found that the inclusion of the 'Ecocorn' additive in fermented wholecrop wheat increased milk yields by 6.2% (Heron 1996).

The increased DM intake associated with the inclusion of CBWCS in mixed forage rations is known to reduce acidosis problems associated with a pure grass silage diet, with a consequent increase in the health and fertility of dairy cattle (Heron 1996). Another nutritional benefit of CBWCS is its much lower buffering capacity than grass silage, and this allows the dairy cow to maintain a stable rumen pH (Heron 1965). The relatively low crude protein levels in fermented CBWCS and maize (Table 5) often require protein supplementation in order to balance degradable protein with available carbohydrate. However, protein content was higher in barley silage than in wheat and urea-based preservation increases protein levels substantially (Table 5). Minerals and vitamins are generally lacking in both CBWCS and maize silages and supplements may be needed if these feeds constitute a high proportion of the ration (Heron 1996).

Fewer studies have been conducted into the effects of CBWCS on beef cattle although one notable study measured a 7.3% increase in liveweight gain when urea-treated wheat wholecrop was included as 25% of the feed (Tetlow & Wilkinson 1992).

Table 5. Comparative feed quality of different silages. Published (Pub) data from Phipps *et al*. (1992) and Heron (1996) are presented along with mean estimates from this study.

Silage		**Grass**	**Maize**	**Wheat**	**Wheat**	**Barley**	**Barley**
				Fermented	Urea	BS	MIN
DM (%)	Pub	20-35	25-35	30-50	50-65		
	This study			52.3	52.3	51.2	50.7
ME (MJ/kgDM)	Pub	10.5-12.0	10.5-11.5	9.5-11.5	9.5-11.5		
	This study			9.9		9.6	9.7
Starch (%DM)	Pub	0	20-30	5-35	20-35		
	This study			26.2		21.9	22.9
Crude protein (% DM)	Pub	12-18	8-10	8-11	15-25		
	This study			10.4		11.2	11.3
D value (%DM)	Pub	65-75	70-75	60-70	60-70		
	This study			62.7		60.6	61.4
pH	Pub	3.7-4.3	3.8-4.3	3.8-4.6	7.5-8.0		
	This study			5.0		5.3	5.3

4.3 Advantages and Disadvantages of CBWCS to livestock farmers

The previous section identifies the main direct benefits to the dairy farmer of substituting CBWCS for some of the grass silage ration as cheaper feed production costs (Table 4), increased dry matter intake (which brings improvements in animal health) and some modest increase in milk protein. The beef farmer can expect increased growth rates of cattle. Other benefits include the high and predictable yield of cereals in all regions of the UK (grass yield is sensitive to drought, while maize still has a restricted growing range), flexibility to delay decisions about whether to harvest for wholecrop or combine for grain (depending on grass production), using CBWCS as a buffer feed in mid-late summer when there may be a lack of grazing, and the absence of the effluent problems associated with grass silage. The earlier harvesting of cereals (compared to maize) provides late summer ground for slurry spreading and allows farmers to grow following catch crops or earlier reseeding with grass (although both these activities are likely to reduce the value of the following winter habitat for foraging birds).

The main disadvantages to the farmer of growing CBWCS are the risks of spoilage in the silage clamp (although these can be markedly reduced through the use of additives) and the low protein content of the feed (which can be remedied using supplements, urea-preservation or bi-cropping with legumes such as peas or clover). Additional potential barriers to the production of CBWCS are a lack of expertise, experience or machinery for growing, harvesting and preserving cereals for wholecrop, or a lack of local contractors able to do the work. Many farmers currently reliant on grass and maize silages may also be unaware of the potential benefits of growing cereals for wholecrop implying a potential role for knowledge transfer.

5. Implications of the study

The ELS scheme offer payments to farmers to encourage the growing of cereals for wholecrop silage production. ELS option EG4 offers 230 points per ha (up to a maximum of 5ha) to grow autumn- or spring-sown cereals for wholecrop production followed by overwinter stubbles which must be retained until mid February (Defra 2005). The cereals must receive no insecticide between 15 March and harvest and herbicide application is restricted to the amidosulfuron (the same product used in the BAR-MIN treatment in this study) during February and March. The BAR-MIN treatment tested in this study would therefore qualify for ELS points although it is likely that most wholecrop cereal now being grown in England with Environmental Stewardship support (includes ELS, HLS and the equivalent organic schemes) is winter wheat.

Although we have not directly tested a ‘minimal-herbicide wheat followed by winter stubbles’ treatment, this study has shown that winter-sown wheat without restrictions on inputs provides an attractive foraging habitat for a range of farmland birds in summer (including granivores, buntings and skylarks). Previous studies have shown that wheat stubbles following crops grown without constraints on herbicide usage are attractive to a range of priority farmland birds during winter (Bradbury & Allen 2003, Bradbury *et al*. 2005), while other studies have shown winter usage of cereal stubbles by farmland birds to be negatively related to herbicide application in the preceding crop and/or cover of plants providing potential seed food (Bradbury *et al.* 2008). Thus, a winter stubble following winter wheat subject to a minimal herbicide restriction is likely to provide food rich habitat for seed-eating birds.

The main challenge for Defra and Natural England is to encourage greater takeup of ELS option EG4. Uptake of CBWCS by May 2007 was limited to 765ha in 176 ELS agreements, plus 136ha in 26 organic ELS agreements (ES uptake statistics, Defra). Only 70ha was included in HLS agreements. Encouraging greater uptake is especially important in grass-dominated landscapes where availability of winter cereal stubbles appears to limit the populations of a range of seed-eating priority farmland birds (Robinson *et al.* 2001). Recent work suggests that only when cereal stubbles account for at least 10% of the area in grass dominated landscapes do populations of yellowhammers and skylarks become sustainable (Gillings *et al.* 2005). However, a high proportion of the stubbles in this study would have followed conventional cereal management including broad-spectrum herbicide application. Thus, the area of cereal stubbles following cereals restricted to narrow-spectrum herbicide treatment needed to sustain farmland bird populations is likely to be less than 10% of the land area. Thus, CBWCS's could play a key role in halting and reversing population declines of a wide range of farmland birds in grass-dominated landscapes where mixed farming and cereal production may have been replaced by intensively managed grassland and maize, both relatively hostile crops to farmland birds.

It is important to stress that our conclusions relating to the benefits of CBWCS to farmland birds relate only to relatively intensive livestock areas (like the West Midlands of England) where farmland is dominated by intensive grassland and maize, both of which are relatively hostile habitats to most priority farmland birds. In areas with more traditional, low-intensity methods of cereal production, the introduction of CBWCS could have negative impacts on farmland birds. An example of this would be the Western Isles of Scotland where traditional cereal production for livestock entails the reaper-binder harvesting of fully ripe grain which is then stacked outdoors over winter. The replacement of this system by wholecrop silage (with earlier harvesting and silage storage in clamps) has probably been a major cause of the decline of corn buntings *Emberiza calandra* in the Western Isles of Scotland (Wilson *et al*. 2007).

6. Future work.

6.1. Further research is needed to identify the main barriers deterring livestock farmers from growing wholecrop silage as a partial substitute for grass or maize. This research should also consider barriers to the adoption of wholecrop cereals (option EG4) as part of ELS agreements.

6.2. In this study maize generally provided relatively little in the way of food resources (invertebrates in summer, or seed-bearing plants during winter) for most priority farmland birds. Further research is needed to investigate means of promoting bird food resources on this crop (e.g. reduced herbicide inputs) and also lapwing nesting success (e.g. by reducing the number and duration of mechanical operations during May). The use of atrazine has recently been banned in the EU so farmers are now seeking effective alternatives.

6.3. Anecdotal observations suggest that various alternative CBWCS and bi-crops (such as triticale *Triticale hexaploide* and lupins *Lupinus angustifolia* or peas now popular among organic farmers) are attractive to priority farmland birds. It would be useful to formally assess these bi-crop combinations with a possible view to encouraging their production through ELS or the Organic Entry Level Scheme.

7. Action resulting

There is a clear need for more effective knowledge transfer to farmers and relevant Defra/Natural England staff regarding the potentially substantial biodiversity benefits of CBWCS, as well as the agronomic benefits and relatively modest costs of producing CBWCS especially under the ELS option. Key messages to stress are the large potential benefits of low-input cereal production to a wide range of priority farmland birds during summer and, if stubbles follow, winter. The benefits to farmland birds are likely to be greatest in areas dominated by intensive livestock production (with large areas of intensively managed grassland and maize) where safe nesting and food-rich foraging habitats are likely to be absent or rare. Key messages for farmers considering growing CBWCS should include the relatively high yields (especially winter wheat), predictable yield (more tolerant than grass of dry growing conditions), relatively low production costs, nutritional benefits to cattle associated with an increased dry matter intake rate and the absence of any serious effluent problems. Growing cereals also allows the livestock farmer to delay decisions about whether to harvest early for wholecrop or delay for grain until his/her grass silage yields are known. This flexibility is likely to be attractive especially when grain commodity prices are high. Further consideration should be given to the barriers deterring livestock farmers from growing CBWCS and the reasons for the currently low uptake of wholecrop silage options in ELS and HLS.

References

Beaton, C., Catto, J. & Kerr, G. (2007) The Farm Management Handbook 2007/08. Scottish Agricultural College.

Bradbury, R.B. & Allen, D.S. (2003). Evaluation of the impact of the pilot UK arable stewardship scheme on breeding and wintering birds. *Bird Study*, 50, 131-141.

Bradbury, R.B., Brown, S.J., Stevens, D.K. & Aebischer, N.A. (2004). Five-year evaluation of the impact of the Arable Stewardship Pilot Scheme on birds. *Ibis* (Supplement 2), 171-180.

Bradbury, R.B., Bailey, C.M., Wright, D., & Evans, A.D. (2008). Wintering cirl buntings in southwest England select cereal stubbles that follow a low-input herbicide regime. *Bird Study*, **55**, 23-31.

Brickle, N.W., Harper, D.G.C., Aebischer, N.J. & Cockayne, S.J. (2000). Effects of agricultural intensification on the breeding success of corn buntings. J. Appl. Ecol. 37, 742-755.

Buckingham, D.L., Peach, W.J. & Fox, D.S. (2006). Effects of agricultural management on the use of lowland grassland by foraging birds. *Agriculture Ecosystems & Environment*, **112,** 21-40.

Buckingham, D.L. & Peach, W.J. 2006. Leaving final-cut grass silage in situ as a winter seed resource for declining farmland birds. *Biodiversity & Conservation*, **15**, 3827-3845.

Defra (2005). Entry Level Stewardship Handbook. Defra, London.

Donald, P.F., Evans, A.D., Muirhead, L.B., Buckingham, D.L., Kirby, W.B. &Schmitt, S.I.A. (2002). Survival rates, causes of failure and productivity of skylark nests on lowland farmland. *Ibis*, **144**, 652-664.

Evans, A.D., Smith, K.L., Buckingham, D.L. & Evans, J. (1997). Seasonal performance and nestling diet of cirl buntings in England. *Bird Study*, **44**, 66-79.

Gillings, S., Newson, S.E., Noble, D.G. & Vickery, J.A. (2005). Winter availability of cereal stubbles attracts declining farmland birds and positively influences breeding population trends. Proc. Roy. Soc. Series B., 272, 733-739.

Heron, S. (1996). Wholecrop Cereals. Zeneca Bio Products.

Holland, J. M., Southway, S., Ewald, J. A., Birkett, T. & Begbie, M. (2002) Invertebrate chick food for farmland birds: spatial and temporal variation in different crops. Aspects of Applied Biology, **67**(Birds & Agriculture), 27-35.

Holland, J.M. & Reynolds, C.J.M. (2003). The impact of soil cultivation on arthropod emergence on arable land. Pedobiologia, 47, 181-191.

Holland, J.M., Hutchison, M.A.S., Smith, B. & Aebischer, N.J. (2006). A review of invertebrates and seed-bearing plants as food for farmland birds in Europe. Annals of Applied Biology, 148, 49-71.

Littell, R.C., Milliken, G.A., Stoup, W.W. & Wolfinger, R.D. (1996). SAS system for mixed models. SAS Institute Inc., Cary, NC, USA.

Marshall, E.J.P. (1989) Distribution patterns of plants associated with arable field edges. *Journal of Applied Ecology*, **26**, 247-257.

Milsom, T.P., Langton, S.D., Parkin, W.K., Peel, S., Bishop, J.D., Hart, J.D. & Moore, N.P. (2000). Habitat models of bird species' distribution: an aid to the management of coastal grazing marshes. *J. Appl. Ecol*., **37**, 706-727.

Moran, M.D. (2003). Arguments for rejecting the sequential Bonferroni in ecological studies. *Oikos*, **100**, 403-405.

Moreby, S.J. & Southway, S.E. (1999) Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture Ecosystems & Environment*, **72**, 285-297.

Morris, A.J., Wilson, J.D., Whittingham, M.J & Bradbury, R.B. (2005). Indirect effects of pesticides on breeding yellowhammer. *Agriculture Ecosystems & Environment*, **106**, 1-16.

Morris, A.J., Holland, J.M., Smith, B., & Jones, N.E. (2004) Sustainable Arable Farming For an Improved Environment (SAFFIE): Managing winter wheat sward structure for Skylarks *Alauda arvensis*. *Ibis*, **146**, 155-162.

Mortimer, A. M. (1990). The biology of weeds. In: *Weed Control Handbook: Principles*, 8th Edition, (Eds Hance, R.J., Holly, K.), pp 1-42. Blackwell Scientific, Oxford.

Newton, I. (1967). The adaptive radiation and feeding ecology of some British finches. *Ibis*, **109**, 33-98.

Nix, J. (2008). 2007 Farm Management Pocketbook. 38th Edition. The Andersons Centre.

Phipps, R.H., Sutton, J.D. & Jones, B.A. (1995). Forage mixtures for dairy cows: the effect on dry-matter intake and milk production of incorporating either fermented or urea-treated whole-crop wheat, brewers' grains, fodder beet or maize silage into diets based on grass silage. *Animal Science*, **61**, 491-496.

Rands, M.R.W. (1985). Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. *J. Appl. Ecol.,* **22**, 49-54.

Robinson, R. A. and Sutherland, W. J. (1999). The winter distribution of seed-eating birds: habitat structure, seed density and seasonal depletion. *Ecography*, **22**, 447-454.

Robinson, R.A, Wilson, J.D. & Crick, H.Q.P. (2001). The importance of arable habitat for farmland birds in grassland landscapes. *J. Appl. Ecol*., 38, 1059-1069.

Schabenberger, O. & Pierce, F.J. (2002) *Contemporary Statistical Models for the Plant and Soil Sciences.* CRC Press, London, UK.

Sheldon, R. D. (2002). Factors affecting the distribution, abundance and chick survival of the lapwing. PhD thesis, Harper Adams University College. Edgemont, Shropshire.

Simpkin, A.P. (2002). Productivity, nest success and chick survival of the lapwing on pasture and arable land in the Dee catchment. Unpublished report to RSPB and the University of Wales, Bangor.

Speight M. R. & Lawton J. H. (1976) Influence of weed-cover on mortality imposed on artificial prey by predatory ground beetles in cereal fields. *Oecologia* **23(3),** 211-223.

Stace, C. (1997) *New Flora of the British Isles* Cambridge University Press, Cambridge, UK.

Tetlow, R.M. & Wilkinson, J.M. (1992). Whole-crop cereals for beef cattle. In *Whole-crop Cereals*, 2nd edn., (Eds. B.A. Stark & J.M. Wilkinson), Chalcombe Publications, Kingston, nr Canterbury, pp. 73-84.

Tucker, G.M. (1992). Effects of agricultural practices on field use by invertebrate-feeding birds in winter. *J. Appl. Ecol.*, **29**, 779-790.

Whittingham, M.J. & Evans, K.L. (2004). A review of the effects of habitat structure on predation risk of birds in agricultural landscapes. Ecology & Conservation of farmland birds. II. The road to recovery. Ibis, 146 (supplement 2), 211-222.

Wilson, A.M., Vickery, J.A. & Browne, S.J. (2001). Numbers and distribution of Northern Lapwing breeding in England and Wales in 1998. *Bird Study,* **48**, 2-17.

Wilson, J.D., Morris, A.J., Arroyo, B.E., Clark, S.C. & Bradbury, R.B. (1999). A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. *Agriculture Ecosystems & Environment*, **75**, 13-30.

Wilson, J.D., Evans, J., Browne, S.J., King, J.R. (1997). Territory distribution and breeding success of skylarks on organic and intensive farmland in southern England. *J. Appl. Ecol*., 34, 1462-1478.

Wilson, J.D., Boyle, J., Jackson, D.B., Lowe, B. & Wilkinson, N.I. (2007). Effect of cereal harvesting methods on a recent population decline of Corn Buntings on the Western Isles of Scotland. *Bird Study*, 54, 362-370.

Wilson, P.J. & King, M. (2003). The biology of arable plants. In *Arable Plants - a Field Guide*, pp. 42-47. Hanway Press, London, UK.

Young, J.E.B., Griffin, M.J., Alford, D.V., & Ogilvy, S.E. (2001) *Reducing agrochemical use on the arable farm: the TALISMAN and SCARAB projects* Defra, London, UK.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Lewis, P. (2004). **Wholecrop cereals in UK agriculture – a briefing report covering current practices and research findings.** Harper Adams University College.

Mortimer, S.R., Westbury, D.B., Dodd, S., Brook, A.J., Harris, S.J., Kessock-Philip, R., Chaney, K., Lewis, P., Buckingham, D.L. & Peach, W.J. (2007) Cereal-based whole crop silages: potential biodiversity benefits of cereal production in pastoral landscapes. **Aspects of Applied Biology**, 81, 77-86

Peach, W., Dodd, S., Westbury, D., Mortimer, S., Harris, S., Brook, A., Lewis, P., Buckingham, D. & Chaney, K. (2007). Cereal-based wholecrop silage: a potential conservation measure for farmland birds in pastoral landscapes. Pages 58-63 in Hopkins, J.J. (ed) **High Value Grassland: providing biodiversity, a clean environment and premium products.** Occasional Symposium No.38, British Grassland Society, Cirencester.