*Bird Study* (2005) **52,** 173–179

# Effect of non-inversion tillage on field usage by UK farmland birds in winter

HEIDI M. CUNNINGHAM[1]*, RICHARD B. BRADBURY[2], KEITH CHANEY[1] and ANDREW WILCOX[1]

*[1]Harper Adams University College, Newport, Shropshire, TF10 8NB, UK and [2]Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire, SG19 2DL, UK*

**Capsule** Several guilds of wintering farmland birds showed preferences for cereal fields established by non-inversion tillage, rather than ploughing.

**Aims** To compare the effects of cereal crop establishment methods using non-inversion tillage and ploughing on field use by wintering farmland birds.

**Methods** Cereal fields on commercial farms, established by non-inversion tillage or conventional ploughing, were censused for birds over the winter months of 2000 to 2003, using standard whole-field count methodologies. Multivariate logistic regression methods were used to assess the difference in bird use between fields with the two crop establishment methods, whilst controlling for the effects of a variety of other variables.

**Results** In late winter, Skylarks *Alauda arvensis*, granivorous passerines and gamebirds occupied a greater proportion of fields established by non-inversion tillage than conventional tillage.

**Conclusions** As well as documented benefits for resource protection, such as soil and water conservation, non-inversion tillage methods appear to enhance suitability of winter cereal fields for foraging birds. Future studies could usefully identify the mechanisms, in terms of food abundance and sward structure, which drive these preferences.

The population and range of many farmland birds have shown substantial declines in the UK over the past few decades (Fuller *et al.* 1995, Siriwardena *et al.* 1998a, Gregory *et al.* 2003). Many of these species, including Skylark *Alauda arvensis*, Song Thrush *Turdus philomelos*, Linnet *Carduelis cannabina*, Yellowhammer *Emberiza citrinella* and Grey Partridge *Perdix perdix*, are now on the UK Red List of species of conservation concern (Gregory *et al.* 2002). A large body of evidence now links many of these declines to aspects of agricultural intensification (Aebischer *et al.* 2000, Anderson *et al.* 2001, Boatman *et al.* 2002) and, across Europe, the extent of national population decline is correlated with various indices of intensification of agricultural production (Donald *et al.* 2001). These declines are of so much concern in the UK that a wildlife 'indicator' based on the population trends of farmland birds is now used as a 'headline' indicator of the sustainability of UK lifestyles (Gregory *et al.* 2003).

Many farmland bird species rely on seeds as food in winter and, for many granivorous species, reduced survival seems to be the current most limiting demographic rate (Siriwardina *et al.* 1998b, 1999, Peach *et al.* 1999). Possible reasons for changes in survival include lack of winter seed food, caused by increased pesticide use, improved harvesting efficiency, bird-proofing of food stores, and the loss of winter stubbles with the switch from spring to autumn sowing of cereals. Consequently, granivorous birds show pronounced aggregative responses to stubbles (Wilson *et al.* 1996), set-aside (Buckingham *et al.* 1999), game feeders (Brickle & Harper 2000) and game cover crops (Stoate *et al.* 2003). Provision of such habitats is now a key measure in UK agri-environment schemes (Evans *et al.* 2002, Bradbury & Allen 2003), and has delivered population recovery of the English Cirl Bunting *Emberiza cirlus* population (Peach *et al.* 2001).

Against this background, non-inversion tillage (NIT) is potentially another means of enhancing winter food for farmland birds. This is a method of preparing a seedbed to establish a crop from the stubble of the previous crop. NIT is a broad term that

*Correspondence author. Email: hcunningham@harper-adams.ac.uk

encompasses different methods that use a combination of tines, discs and harrows, rather than the conventional mouldboard plough. While the plough, or conventional tillage, inverts the soil to depths of approximately 20–25 cm, NIT methods disturb the soil to shallower depths of typically 10–15 cm. NIT is also referred to as reduced tillage, no-till, ECOtillage, minimum tillage (min till) and conservation tillage, the latter being a term often used in North America (Stride & Wright 1997).

While a ploughing system relies on burial of weeds and seeds for weed control, NIT systems rely on use of herbicides to control weeds that emerge from the post-harvest stubble. From an agronomic perspective, the adoption of NIT may lead to a greater susceptibility to grass weeds, although modern and more refined chemical weed control methods can be used to minimize this problem (Stride & Wright 1997). This method is gaining popularity due primarily to the reduced cost of crop establishment. If implemented successfully, NIT can reduce mineralization and leaching of soil nitrogen, overall herbicide needs and the risk of soil erosion. Significant savings in terms of labour, fuel and time can be made with NIT when compared to conventional mouldboard ploughing (Ball 1989, Sijtsma *et al.* 1998) without incurring losses in yield, at least on some soil types (Chaney *et al.* 1985). The retention of vegetative cover with NIT also provides soil and water conservation benefits. It is therefore likely that NIT will become a more widespread practice in Europe, independent of any need for additional financial incentive for helping biodiversity (e.g. Birkas *et al.* 1989). Given additional potential to enhance soil and water conservation, it may well prove to be a useful tool for countries that recently joined the European Union, to produce competitively priced crops whilst minimizing environmental impact (Donald *et al.* 2002).

Ground-nesting birds have been observed at higher densities in no-till and NIT fields than ploughed fields in North America (Basore *et al.* 1986, Flickinger & Pendleton 1994, Lokemoen & Beiser 1997, Martin & Forsyth 2003). In addition to providing more favourable conditions for nesting, establishing crops using non-inversion tillage systems may enhance food resources for birds. Granivorous passerines such as Yellowhammers are dependent on seeds (Wilson *et al.* 1999). In winter, such species may benefit from lack of burial of spilled grain and weed seeds produced in the previous crop. Soil-dwelling and surface-active invertebrates such as earthworms, beetles and spiders may potentially benefit from NIT, as the detrimental effects of ploughing on these invertebrates has been well documented (Edwards & Lofty 1982, Ferguson & McPherson 1985, Barker *et al.* 1999). In winter, thrushes and Lapwings *Vanellus vanellus*, may also be able to take advantage of provision of such food resources. A study in Texas showed that several bird species benefited from minimum tillage in winter, though preferences by individual species were influenced by the impact on that species of enhanced vegetative cover under minimum tillage regimes (Flickinger & Pendleton 1994). The effect of cover on each species depends on how the benefit of cover from predators trades off against the increased difficulty in finding and accessing food resources in denser swards.

In Europe, comparatively little research has been carried out to evaluate the effects of NIT on farmland biodiversity (e.g. Kromp 1999, Streit *et al.* 2002). Here we present the results of a three-year study in the UK to investigate the relative field usage by birds on winter wheat and barley fields established by non-inversion tillage and conventional ploughing.

## METHODS

### Study area

Winter wheat and barley fields established by either NIT or conventional tillage (CT) were censused for birds on commercial farms in Oxfordshire, Leicestershire and Shropshire, UK. Censuses took place once a month between October and March, in three consecutive cropping years from 2000 to 2003. Leicestershire and Shropshire were censused in all three years, but Oxfordshire was censused only in winter 2000/1, due to logistical constraints. In each year of the study between seven and nine farms were visited. Cereals were followed in crop rotation, so the same fields were not censused in all years. In all, 121 different fields were censused at least once. Previous crop types included winter wheat, winter barley, oilseed rape, peas, beans, maize, carrots, grass, oats, and set-aside (Table 1). Field area refers to the area of crop within the field, excluding field boundaries and margins, and ranged from 1.63 to 22.27 hectares.

### Survey method

Birds were censused using binoculars by walking the cropped area of fields using straight line transects 50 m

**Table 1.** Variables used in the analyses of variation in field occupancy.

| Variable | Type | Factor levels | *n** (NIT, CT) |
|---|---|---|---|
| Field area | Continuous variable | | |
| Tillage | Two-level fixed factor | Non-inversion tillage (NIT) | 63 |
| | | Conventional tillage (CT) | 58 |
| Crop type | Two-level fixed factor | Winter wheat | 105 (59,46) |
| | | Winter barley | 16 (4,12) |
| Year | Three-level fixed factor | 2000/1 | 20 (10,10) |
| | | 2001/2 | 53 (29,24) |
| | | 2002/3 | 48 (24,24) |
| Previous crop | Five-level fixed factor | Cereal (winter wheat, winter barley, maize, oats) | 43 (17, 26) |
| | | Oil seed rape | 24 (13, 11) |
| | | Set-aside | 28 (17, 11) |
| | | Legumes and carrots (peas, beans, carrots) | 20 (14, 6) |
| | | Grass | 6 (2, 4) |
| Farm | Nine-level random effect | | |

*Number of fields relating to a given factor.

**Table 2.** Bird groups used in analyses.

| Group | Bird species included in group |
|---|---|
| Skylarks | Skylarks *Alauda arvensis* |
| Gamebirds | Grey Partridge *Perdix perdix*, Red-legged Partridge *Alectoris rufa*, Pheasant *Phasianus colchicus* |
| Insectivores | Blackbird *Turdus merula*, Fieldfare *Turdus pilaris*, Lapwing *Vanellus vanellus*, Meadow Pipit *Anthus pratensis*, Mistle Thrush *Turdus viscivorus*, Pied Wagtail *Motacilla alba*, Redwing *Turdus iliacus*, Robin *Erithacus rubecula*, Starling *Sturnus vulgaris* |
| Granivorous passerines | Chaffinch *Fringilla coelebs*, Goldfinch *Carduelis carduelis*, Greenfinch *Carduelis chloris*, Linnet *Carduelis cannabina*, Yellowhammer *Emberiza citrinella* |
| Corvids | Carrion Crow *Corvus corone*, Rook *Corvus frugilegus*, Magpie *Pica pica*, Jay *Garrulus glandarius* |
| Pigeons | Woodpigeon *Columba palumbus*, Stock Pigeon *Columba oenas*, Feral Pigeon *Columba livia* |

apart, in order to flush all the birds present (Perkins *et al.* 2000, Bradbury & Allen 2003). All birds flushed were identified to species and counted. Birds seen flying over fields were not counted. Double counting of birds was minimized by the observer taking into account birds that were flushed to other fields or to other parts of the field being censused. In practice most birds that left the observation field simply moved to the neighbouring field, so it was relatively easy to account for them when counting that field. However, a small amount of double-counting is probably inherent in the data. Despite this small drawback, we considered this a better method than counting from the field edge, without flushing, which in our experience can fail to detect many birds. To ensure that birds travelling to and from their night roosts were not counted, censuses were not performed in the hour after sunrise and the hour before sunset. Censuses were not performed on days with strong wind or heavy rain, as this may have affected bird behaviour (Bibby *et al.* 1992).

### Statistical analysis

The bird counts were grouped into six response variables: Skylarks, gamebirds, insectivores, granivorous passerines, corvids and pigeons (Table 2). Skylarks were considered separately because of their ability, not shared with other granivorous passerines, to eat growing shoots of crops (Green 1978).

The bird counts were collated for two periods over the winter for each year: the early (October to December) and late (January to March) winter periods. Splitting the data into these two periods allowed any differences between CT and NIT to be assessed at different stages of crop development, at periods sooner and later after crops were established by the two tillage methods and after depletion or replenishment of food resources may have occurred.

Analyses were performed using generalized linear mixed models (Lawes Agricultural Trust 2000). We analysed variation in field usage, with presence or absence of each guild in each field at any point during

**Table 3.** General logistic regression analysis (GLMM) of field occupancy in the early winter period (pre-31 December) and in the late winter period (post-31 December).

| | Early winter period | | | Late winter period | | |
|---|---|---|---|---|---|---|
| Response variable | Wald statistic | df | $P$ ($\chi^2$) | Wald statistic | df | $P$ ($\chi^2$) |
| Skylarks | 2.59 | 1 | 0.107 | 6.64 | 1 | **0.010** |
| Gamebirds | 0.16 | 1 | 0.685 | 7.91 | 1 | **0.005** |
| Insectivores | 0.10 | 1 | 0.753 | 0.00 | 1 | 0.974 |
| Granivorous passerines | 1.01 | 1 | 0.315 | 4.14 | 1 | **0.042** |
| Corvids | 0.04 | 1 | 0.849 | 0.00 | 1 | 0.976 |
| Pigeons | 1.52 | 1 | 0.218 | 1.22 | 1 | 0.269 |

Entries in bold indicate significantly greater occupancy by birds of NIT fields than CT fields.

the time period as a response variable, using general logistic regression. Analysis of field occupancy, rather than counts, helps to eliminate potential problems of non-independence of individuals within a flock. A binomial error and logit link function were specified, controlling for overdispersion.

The effect of tillage (a two-level fixed factor) on field occupancy was tested whilst controlling for significant effects of the following factors: year (a three-level fixed factor), crop type (a two-level fixed factor), previous crop type (a five-level fixed factor), and farm identity (random effect). Minimum Adequate Models were reached by step-down model simplification. The natural log of field size was defined as an offset to control for the probability of encountering birds more often by chance in bigger fields. Due to problems with lack of convergence of the multivariate model, the late winter gamebird analysis was run as a univariate test (i.e. the model was run with tillage as the only explanatory variable). Significance testing was achieved by calculating the Wald statistic, and comparing this with the $\chi^2$ distribution ($\alpha = 0.05$). The significance of the tillage factor was tested using $\alpha = 0.05$, whereas the other nuisance factors in the model were retained if significant at $\alpha = 0.10$.

## RESULTS

In the early winter period, no differences in field occupancy were observed between fields established by NIT and CT, for any of the guilds, including skylarks, granivorous passerines, gamebirds, insectivores, corvids and pigeons (Table 3, Fig. 1). In the late winter period, gamebirds, Skylarks and granivorous passerines all occupied a greater proportion of fields established by non-inversion tillage (Table 3, Fig. 2), whereas no differences in field occupancy were observed for insectivores, corvids or pigeons in the same winter period.

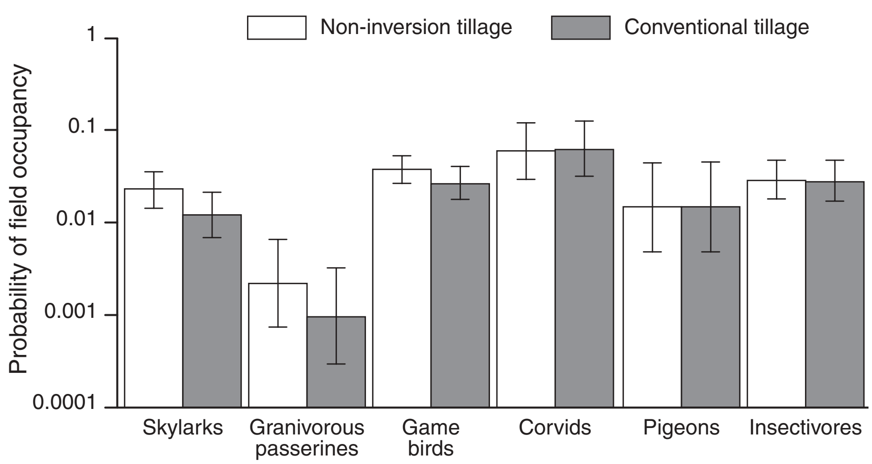


**Figure 1.** Back-transformed probability of occupancy of fields established by non-inversion tillage and conventional tillage in the early winter period (October to December). Error bars indicate upper and lower 95% confidence limits.

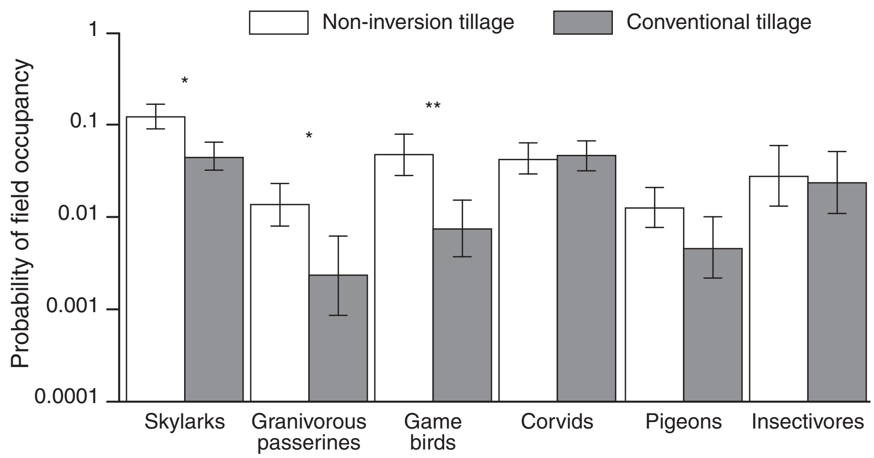


**Figure 2.** Back-transformed probability of occupancy of fields established by non-inversion tillage and conventional tillage in the late winter period (January to March). $*P < 0.05$, $**P < 0.01$. Error bars indicate upper and lower 95% confidence limits.

No great differences within the bird guilds were observed, in terms of number of species, except for granivorous passerines, where more species were observed in fields established by NIT than those established by CT (Table 4).

## DISCUSSION

This study shows several instances of positive responses to NIT, by a range of granivorous birds in late winter. Seeds are an important part of the diet of all these bird taxa in winter (Green 1978, Wilson *et al.* 1999), so these results indicate that NIT may increase the availability of weed seeds for granivorous birds. Seed availability will be determined partly by seed abundance and partly by access to seeds, which itself is largely determined by sward structure (e.g. Perkins *et al.* 2000, Moorcroft *et al.* 2002). It would be interesting to quantify seed abundance at the soil surface in NIT systems, as the lack of ploughing and greater herbicide use may leave more seed available at, or nearer, the surface. However, given that the surface of a NIT field is more complex, because of retained stubble trash, than a ploughed field, it is perhaps likely that access will be more impaired on a NIT field. Whittingham & Markland (2002) have shown significantly increased intake rates and lower search time for seeds by birds on a bare earth substrate compared with a short grass sward.

The effects of tillage on field occupancy were much stronger in the late winter period (i.e. from January to March). This suggests that, as food resources become scarcer over the winter, fields established by NIT may retain or encourage a greater abundance of bird food, or at least not become depleted to below thresholds where foraging becomes unproductive. It is possible that, because seedling emergence is strongly related to burial depth (Grundy *et al.* 1996), seedlings may re-establish more quickly on NIT fields, and so replenish seed resources.

As NIT generally disturbs the soil to a more shallow depth than CT, mortality rates of invertebrates may be lower and therefore populations on NIT fields may recover more quickly. Greater amounts of crop residue at the surface may also provide a more suitable micro-climate for invertebrates to inhabit and over-winter nearer the soil surface on NIT fields than CT fields. However, insectivorous birds showed no response to NIT. This may be because, due to paucity of data, data for an eclectic group of species were pooled, including species such as Lapwings, Robins *Erithacus rubecula* and Mistle Thrushes *Turdus viscivorus*. These birds have a wide range of feeding strategies (some picking at the surface and others probing) and some prefer the field

**Table 4**. Number of species observed in each guild.

| | Early winter period | | Late winter period | |
|---|---|---|---|---|
| Response variable | NIT | CT | NIT | CT |
| Skylarks | 1 | 1 | 1 | 1 |
| Gamebirds* | 2 | 2 | 2 | 2 |
| Insectivores | 9 | 6 | 6 | 6 |
| Granivorous passerines* | 2 | 1 | 5 | 1 |
| Corvids* | 3 | 2 | 2 | 1 |
| Pigeons** | – | – | – | – |

*Minimum number of bird species observed.
**No information available.

edge and some the field centre. Therefore, their food requirements may be affected by tillage in different ways. Alternatively, the types of invertebrates in the diets of these birds may reach such a low level of abundance or availability in winter in this habitat, compared to others, that tillage effects on insectivorous birds are trivial and undetectable. However, it is perhaps surprising that no responses were detectable across groups such as plovers and thrushes, given the strong prediction of enhanced earthworm (e.g. Edwards & Lofty 1982, Clapperton *et al.* 1997, Kladivko *et al.* 1997) and soil-surface arthropod populations (e.g. Stinner & House 1990, Carcamo 1995, Kromp 1999), under NIT regimes.

There are signs that Common Agricultural Policy reform will enable agricultural systems in the UK and across Europe to move from intensive crop production towards more sustainable agriculture. In addition to sustaining biodiversity, establishing crops by non-inversion tillage has been shown to have many other resource protection benefits, such as soil conservation, water conservation and carbon sequestration (Triplett & van Doren 1977). Indeed, NIT was developed primarily to solve many issues regarding arable soil degradation, including erosion and the loss of soil structure. This study shows that NIT also seems to have a positive impact on biodiversity, in terms of winter birds, in the UK. This corroborates studies outside Europe, such as the USA and Canada (e.g. Flickinger & Pendleton 1994, Martin & Forsyth 2003). It is therefore encouraging that reduced tillage options have been included, currently primarily for resource protection reasons, in the new entry-level agri-environment scheme in England. While wheat and barley cereal crops have been the main focus of this study, it is important to examine whether these differences are seen across other crops, such as oilseed rape. Further studies should also investigate specifically the effect of different tillage regimes on abundance of, and access to, weed seeds and invertebrates, to identify the mechanisms behind these bird responses.

## ACKNOWLEDGEMENTS

Harper Adams University College and the RSPB funded this project. Thanks are due to the many farmers and landowners, too many to mention by name here, who have allowed access to their fields. Particular thanks are due to Alastair Leake and Chris Stoate at Loddington, Peter Thompson and Nick Padwick at Farmcare Stoughton, Leicestershire, and Katy James at the Northmoor Trust, Oxfordshire. Thanks are due to the support given by the Soil Management Initiative and to Jerry Wilson for initial discussions. Tony Morris and Will Peach gave statistical advice.

## REFERENCES

**Aebischer, N.J., Evans, A.D., Grice, P.V. & Vickery, J.A. (eds)** 2000. *Ecology and Conservation of Lowland Farmland Birds*. British Ornithologists' Union, Tring, UK.

**Anderson, G.Q.A., Bradbury, R.B. & Evans, A.D.** 2001.*Evidence for the effects of agricultural intensification on wild bird populations in the UK*. RSPB Research Report No 3. RSPB, Sandy, UK.

**Ball, B.C.** 1989. Reduced tillage in Great Britain: practical and research experience. In Baumer, K. & Ehlers, W. (eds) *Energy Saving by Reduced Soil Tillage*: 29–40. Office for Official Publications of the European Communities, Luxembourg.

**Barker, A.M., Brown, M.J. & Reynolds, C.J.M.** 1999. Do host-plant requirements and mortality from soil cultivation determine the distribution of graminivorous sawflies on farmland? *J. Appl. Ecol.* **36:** 271–282.

**Basore, N.S., Best, L.B. & Wooley, J.B. Jr** 1986. Bird nesting in Iowa no-tillage and tilled cropland. *J. Wildl. Manage.* **50:** 19–28.

**Bibby, C.J., Burgess, N.D. & Hill, D.A.** 1992. *Common Bird Census*. Academic Press, London.

**Birkás, M., Antal, J. & Dorogi, I.** 1989. Conventional and reduced tillage in Hungary – a review. *Soil Tillage Res.* **13:** 233–252.

**Boatman, N.D., Carter, N., Evans, A.D., Grice, P.V., Stoate, C. & Wilson, J.D.** 2002. *Birds and Agriculture*. Aspects of Applied Biology 67. Association of Applied Biologists, Wellesbourne.

**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.

**Brickle, N.W. & Harper, D.G.C.** 2000. Habitat use by Corn Buntings *Miliaria calandra* in winter and summer. In Aebischer, N.J., Evans, A.D., Grice, P.V. & Vickery, J.A. (eds) *Ecology and Conservation of Lowland Farmland Birds*: 156–164. British Ornithologists' Union, Tring, UK.

**Buckingham, D.L., Evans, A.D., Morris, A.J., Orsman, C.J. & Yaxley, R.** 1999. Use of set aside land in winter by declining farmland bird species in the UK. *Bird Study* **46:** 157–169.

**Carcamo, H.** 1995. Effect of tillage on ground beetles (Coleoptera: Carabidae): a farm-scale study in central Alberta. *Can. Entomol.* **127:** 631–639.

**Chaney, K., Hodgson, D.R. & Braim, M.A.** 1985. The effects of direct drilling, shallow cultivation and ploughing on some soil properties in a long-term experiment on spring barley. *J. Agric. Sci.* **104:** 125–133.

**Clapperton, M.J., Miller, J.J., Larney, F.J. & Lindwall, C.W.** 1997. Earthworm populations as affected by long-term tillage practices in Southern Alberta, Canada. *Soil Biol. Biochem.* **29:** 631–633.

**Donald, P.F., Green, R.E. & Heath, M.F.** 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. *Proc. R. Soc. London* B **268:** 25–29.

**Donald, P.F., Pisano, G., Rayment, M.D. & Pain, D.J.** 2002. The Common Agricultural Policy, EU enlargement and the conservation of Europe's farmland birds. *Agric. Ecosyst. Environ.* **89:** 167–182.

**Edwards, C.A. & Lofty, J.R.** 1982. The effect of direct drilling and minimal cultivation on earthworm populations. *J. Appl. Ecol.* **19:** 723–734.

**Evans, A.D., Armstrong-Brown, S. & Grice, P.V.** 2002. The role of research and development in the evolution of a 'smart' agri-environment scheme. *Aspects Appl. Biol.* **67:** 253–264.

**Ferguson, H.J. & McPherson, R.M.** 1985. Abundance and diversity of adult Carabidae in four soybean cropping systems in Virginia. *J. Entomol. Sci.* **20:** 163–171.

**Flickinger, E.L. & Pendleton, G.W.** 1994. Bird use of agricultural fields under reduced and conventional tillage in the Texas panhandle. *Wildl. Soc. Bull.* **22:** 34–42.

**Fuller, R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R. & Carter, N.** 1995. Population declines and range contractions among lowland farmland birds in Britain. *Conserv. Biol.* **9:** 1425–1441.

**Green, R.E.** 1978. Factors affecting the diet of farmland skylarks *Alauda arvensis* L. *J. Anim. Ecol.* **47:** 913–928.

**Gregory, R.D., Wilkinson, N.I., Noble, D.G., Robinson, J.A., Brown, A.F., Hughes, J., Procter, D.A., Gibbons, D.W. & Galbraith, C.A.** 2002. The population status of birds in the United Kingdom, Channel Islands and Isle of Man: an analysis of conservation concern 2002–2007. *Br. Birds* **95:** 410–450.

**Gregory, R.D., Eaton, M.A., Noble, D.G., Robinson, J.A., Parsons, M., Baker, H., Austin, G. & Hilton, G.M.** 2003. *The State of the UK's Birds 2002*. The RSPB, BTO, WWT and JNCC, Sandy.

**Grundy, A.C., Mead, A. & Bond, W.** 1996. Modelling the effects of weed–seed distribution in the soil profile on seedling emergence. *Weed Res.* **36:** 375–384.

**Kladivko, E.J., Akhouri, N.M. & Weesies, G.** 1997.Earthworm populations and species distributions under no-till and conventional tillage in Indiana and Illinois. *Soil Biol. Biochem.* **29:** 613–615.

**Kromp, B.** 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. *Agric. Ecosyst. Environ.* **74:** 187–228.

**Lawes Agricultural Trust.** 2000. Genstat 5: Release 4.1. Rothamstead Experimental Station.

**Lokemoen, J.T. & Beiser, J.A.** 1997. Bird use and nesting in conventional, minimum-tillage, and organic cropland. *J. Wildl. Manage.* **61:** 644–655.

**Martin, P.A. & Forsyth, D.J.** 2003. Occurrence and productivity of songbirds in prairie farmland under conventional versus minimum tillage regimes. *Agric. Ecosyst. Environ.* **96:** 107–117.

**Moorcroft, D., Whittingham, M.J., Bradbury, R.B. & Wilson, J.D.** 2002. Stubble field prescriptions for granivorous birds – The role of vegetation cover and food abundance. *J. Appl. Ecol*. **39:** 535–547.

**Peach, W.J., Siriwardena, G.M. & Gregory, R.D.** 1999. Long-term changes in over-winter survival rates explain the decline of reed buntings *Emberiza schoeniclus* in Britain. *J. Appl. Ecol.* **36:** 798–811.

**Peach, W.J., Lovett, L.J., Wotton, S.R. & Jeffs, C.** 2001. Countryside stewardship delivers cirl buntings (*Emberiza cirlus*) in Devon, UK. *Biol. Cons.* **101:** 361–373.

**Perkins, A.J., Whittingham, M.J., Bradbury, R.B., Wilson, J.D., Morris, A.J. & Barnett, P.R.** 2000. Habitat characteristics affecting use of lowland agricultural grassland by birds in winter. *Biol. Cons.* **95:** 279–294.

**Sijtsma, C.H., Campbell, A.J., McLaughlin, N.B. & Carter, M.R.** 1998. Comparative tillage costs for crop rotations utilizing minimum tillage on a farm scale. *Soil Tillage Res.* **49:** 223–231.

**Siriwardena, G.M., Baillie, S.R., Buckland, S.T., Fewster, R.M., Marchant, J.H. & Wilson, J.D.** 1998a. Trends in the abundance of farmland birds: a quantitative comparison of smoothed Common Bird Census indices. *J. Appl. Ecol.* **35:** 24–43.

**Siriwardena, G.M., Baillie, S.R. & Wilson, J.D.** 1998b. Variation in the survival rates of some British passerines with respect to their population trends on farmland. *Bird Study* **45:** 276–292.

**Siriwardena, G.M., Baillie, S.R. & Wilson, J.D.** 1999. Temporal variation in the annual survival rates of six granivorous birds with contrasting population trends. *Ibis* **141:** 621–636.

**Stinner, B.R. & House, G.J.** 1990. Arthropods and other invertebrates in conservation-tillage agriculture. *Ann. Rev. Entomol.* **35:** 299–318.

**Stoate, C., Szczur, J. & Aebischer, N.J.** 2003. Winter use of wild bird cover crops by passerines on farmland in northeast England. *Bird Study* **50:** 15–21.

**Streit, B., Rieger, S.B., Stamp, P. & Richner, W.** 2002. The effect of tillage intensity and time of herbicide application on weed communities and populations in maize in central Europe. *Agric. Ecosys. Environ.* **92:** 211–224.

**Stride, C.D. & Wright, P.J.** 1997. ECOtillage: A sustainable management programme which reduces the cost of crop establishment and weed control, whilst providing environmental benefits. In *Brighton Crop Protection Conference – Weeds*: 453–460. BCPC, Brighton, UK.

**Triplett, G.B. Jr & van Doren, D.M. Jr** 1977. Agriculture without tillage.*Sci. Am.* **236:** 28–33.

**Whittingham, M.J. & Markland, H.M.** 2002. The influence of substrate on the functional response of an avian granivore and its implications for farmland bird conservation. *Oecologia* **130:** 637–644.

**Wilson, J.D., Taylor, R. & Muirhead, L.B.** 1996. Field use by farmland birds in winter: an analysis of field type preferences using resampling methods. *Bird Study* **43:** 320–332.

**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. *Agric. Ecosyst. Environ.* **75:** 13–30.

(MS received 26 January 2004; revised MS accepted 3 June 2004)