# SESSION 10B

# HOW TO MANAGE HERBICIDE-RESISTANT WEEDS

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| Papers | 10B-1 to 10B-5 |

# SUCCESS FROM ADVERSITY: HERBICIDE RESISTANCE CAN DRIVE CHANGES TO SUSTAINABLE WEED MANAGEMENT SYSTEMS

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## ABSTRACT

In recent years, multiple resistance to selective herbicides in the grass weed *Lolium rigidum* has become a problem on thousands of southern Australian farms. Multiple resistance, across a wide range of the commonly used selective herbicides, threatens the productivity and sustainability of cropping systems. Multiple resistance has dented the illusion of the invincibility of herbicides to control weed species and exposed the need to develop more integrated weed management strategies. However, paradoxically, the advent of widespread multiple resistance has provided a driving force which has resulted in the development of integrated weed management strategies which are less herbicide reliant. Successful integrated management strategies utilise herbicides and a range of agronomic and cultural techniques to manage weed populations. Experience reveals that integrated strategies, embracing but not wholly herbicide-dependent, can be cost-effective and sustainable. Such integrated strategies are necessary to preserve the continued efficacy of herbicides in the long term.

## HERBICIDE RELIANCE, HERBICIDE RESISTANCE AND CONSEQUENCES

Sustainable management of weed populations in agriculture is critical. In industrialised nations, and increasingly in developing nations, herbicides dominate weed control options. Efficacious, inexpensive herbicides are produced and marketed world-wide by a competitive international agrochemical industry. Farm advisers in both the private and public sector and farmers are very knowledgeable on herbicide technology. In short, for most cropping situations, a herbicide choice exists which gives rapid, if short-term, control of target weeds. By comparison, other methods of weed management (biological or physical control, crop and pasture rotations) are long-term, often more problematic to implement and give variable results which are often less visually effective than evident with herbicides. Given all of these factors it is readily obvious that farmers have and will continue to opt for herbicides as their preferred method of weed control. This focus on herbicide technology to the exclusion of other weed control methods (Swanton and Weise, 1991, Thill *et al*, 1991, Zimdahl, 1991) does not pay sufficient attention to the potent evolutionary forces at work when there is strong selection pressure from one agent (herbicide or otherwise). As discussed below, the challenge for the future is to ensure that herbicides retain their efficacy in the longer-term.

One repercussion from reliance on herbicides is the appearance of herbicide resistant weed biotypes. Herbicide resistance is occurring worldwide, especially in developed nations (see LeBaron and Gressel, 1982, Powles and Holtum, 1994, Powles *et al* 1997). Worldwide, the region with the greatest problems with herbicide resistance is the wheat-belt of southern Australia. This is because the ubiquitous annual grass weed (*Lolium rigidum*) has developed herbicide resistance on thousands of southern Australian farms.

In a survey conducted in March 1997, 17% of the 52,000 southern Australian cropping farmers report herbicide resistance in *L. rigidum* (Solutions Marketing and Research Group Farm Panel Resistance Monitor). In 1994 we randomly collected *L. rigidum* infesting crops within a region of 800,000 hectares devoted to intensive cropping in South Australia and established a massive 40% of the samples displayed herbicide resistance (Nietschke *et al*, 1996).

What makes *L. rigidum* the world's most severe case of herbicide resistance is that most resistant populations display multiple herbicide resistance to a range of herbicides with different modes of action. In the most dramatic cases, multiple resistance in *L. rigidum* extends simultaneously across many separate chemical classes and can include all selective herbicides that would normally provide control (Gill, 1995, Preston *et al*, 1996). As *L. rigidum* is the most important weed of southern Australian cropping, and is frequently present at densities reducing crop yield, the appearance of widespread multiple herbicide resistance poses a significant problem and threatens the sustainability of intensive cropping systems. However, although initially a major constraint to intensive cropping, the advent of multiple herbicide resistance in *L. rigidum* can drive change in weed management strategies which have long-term beneficial effects.

Multiple herbicide resistance while shattering the illusion that herbicides will work forever, is a driving force for the adoption of integrated weed management (IWM) (Powles and Matthews, 1992, Matthews, 1994, Gill and Holmes, 1997). The experience among farmers, advisors and researchers, that multiple resistance cannot be solved by simply reaching for the next available herbicide, has necessitated more holistic weed management strategies. Thus, multiple resistance has had a beneficial impact by forcing the adoption of IWM strategies that would not otherwise have been identified. The advent of multiple resistant *L. rigidum* has required that farmers, advisers and researchers look beyond herbicides as the sole solution to weed problems. As there is the acceptance that herbicides alone are not a sustainable weed management strategy, then other techniques used in combination with herbicides are being identified. Innovative strategies for weed management are flowing (Matthews, 1994, Powles and Matthews, 1996, Gill and Holmes, 1997, Moss, 1997).

## COMPONENTS OF IWM SYSTEMS FOR SOUTHERN AUSTRALIAN CROPPING

Singular and persistant reliance on any single technique for weed management is not sustainable when dealing with weed species with potent capacity to develop avoidance/resistance. This maxim applies not only to herbicides but also for other control techniques if used persistently and in isolation (Mortimer, 1997). In order to be effective and to contribute to profitable and sustainable cropping systems, weed management systems must be multi-faceted as well as making agronomic and economic sense. Weed management must integrate as wide a range of methods as possible within a farming system. The aim of IWM is to ensure cropping systems are managed in a way that sustains profitable production and reduces the risk of specific weeds getting out of control. As *L. rigidum* is often the major weed of concern to southern Australian farmers, and as it has developed multiple resistance, the development of IWM systems for its control has become a necessity (Matthews, 1994). A full range of non-herbicidal techniques for combating herbicide resistant *L. rigidum* has recently been reviewed by Gill and Holmes (1997). Many of these cultural control techniques exploit a key biological feature (weakness) of *L. rigidum*, its short residual life of seed in the soil seedbank. Seed produced at the end of the winter-spring growing season is strongly summer-dormant and then the great majority will germinate following the onset of rainfall at the beginning of the next winter growing season. There is little persistence of viable seed (Monaghan, 1980). Knowledge that the majority of *L. rigidum* seed will germinate early in the growing season and that there is little long-term longevity of seed in the soil seedbank enables the design of IWM systems incorporating various techniques (Matthews, 1994, Gill and Holmes, 1997), including those mentioned below.

Increasing crop competitivity to suppress weeds

The intrinisic ability of crops to compete with weeds has not received due recognition over the period that herbicides have dominated weed control. However, with widespread multiple herbicide resistance in *L. rigidum* in Australia, there is renewed emphasis on the crop as a means to restrict weed growth. It is becoming increasingly accepted that a potent biological method of weed control is to establish healthy, vigorous-growing, densely-established crops which suppress weed growth and seed production. Ways in which crop competitivity can be ensured include:

a) *Crop choice*. Some crop species are more successful than others in competing with weeds. Cereal crops, especially barley, are much more competitive than pulse crops (Lemerle *et al* 1995, Powles and Matthews, 1996). In comparison with barley and wheat, *L. rigidum* infesting pea crops was much more vigourous resulting in much higher seed production (Table 1). Clearly, selection of crop species can be used as part of IWM systems to limit the impact of infesting weed species.

Table 1. Ability of crop species (peas, barley, wheat ) to limit the seed production of infesting *L.rigidum* plants (from Powles and Matthews, 1996)

| | *L. rigidum* seeds/m$^2$ | |
|---|---|---|
| Crop species | Plants | Seeds/plant |
| Peas | 63 | 55.8 |
| Barley | 109 | 4.2 |
| Wheat | 102 | 9.4 |

b) *Crop seeding rate*. Weed growth will fill any niches not occupied by crop plants. One simple means of minimising opportunities for weed species is to sow the crop species at high rates. Medd *et al* (1987) and G. S. Gill (unpublished) established that high wheat seeding rates substantially reduced *L. rigidum* growth and seed production. With the widespread appearance of herbicide resistant *L. rigidum*, Australian farmers are now increasing crop seeding rates by 20-40%, resulting in higher densities of crop plants. At all stages of growth, this increased crop density suppresses weed growth. This simple technique is now being widely adopted by farmers as part of IWM systems.

c) *Crop sowing date*. Seed of *L. rigidum* and other annual weeds do not germinate until the late-autumn rains which herald the start of the winter-growing season. These weeds then emerge as a massive flush of emergence just when crop sowing is occurring. Powles and Matthews (1996) showed that a 21 day delay in wheat sowing date enabled substantial control of *L. rigidum* by the use of non-selective herbicides (or cultivation) before seeding (Table 2). This meant many less *L. rigidum* plants emerging within the wheat crop and obviated the need for in-crop herbicides. Crop yield was not reduced by the 21 day delay in sowing, although in years where rains arrive late then yield will likely be reduced by delayed sowing. This technique can also be used with crop species suited to later sowing dates (eg barley, safflower). Thus, delayed sowing can be a valuable technique within an IWM system.

Table 2. Effect of a 21 day delay in seeding date on the number of mature *L. rigidum* plants in the final crop of the rotation and on the following seedbank (from Powles and Matthews, 1996).

| | *L. rigidum* ($m^{-2}$) | | | |
|---|---|---|---|---|
| | Early sowing | | Sowing 21 day later | |
| Crop species | Plants | Seeds | Plants | Seeds |
| Peas | 106 | 5654 | 20 | 2916 |
| Barley | 173 | 712 | 31 | 210 |
| Wheat | 147 | 1425 | 72 | 318 |

d) *Crop vigour.* Excellent crop agronomy will ensure a vigourous, rapidly-growing crop which will pose formidable competition for emerging weed species. This is especially so when dealing with multiple herbicide resistant *L. rigidum* for which there may not be a selective herbicide effective for in-crop use. Therefore, as part of IWM systems, it is essential that there be attention to agronomic practices, especially crop nutrition, ensuring vigourous crop growth. Farmers successfully managing multiple herbicide resistance ensure that the crop has every agronomic advantage over weed species.

e) *Crop genotypes with superior weed suppression capacity.* At the research level, considerable effort is underway in Australia to identify crop genotypes that are intrinsically more competitive against weeds. Screening of a wide range of wheat genotypes has revealed substantial genetic diversity in competitiveness against weed infestations (Lemerle *et al* 1996, G. S. Gill, unpublished). Clearly, there is considerable scope for selection and possibly also for breeding wheat genotypes for superior competitive ability against weeds. Such genotypes will have a valuable role to play in IWM systems.

Weed seed removal at crop harvest

A promising strategy being pursued by a small number of farmers is the retention of weed seed, principally *L. rigidum*, in the harvesting operation. Various techniques to intercept and retain weed seed include trailing bins, commercially available harvester attachments or modifications to funnel and then burn seed. Powles and Matthews (1996) and G. S. Gill (unpublished) showed that substantial *L. rigidum* seed can be removed in this manner and that seed capture at harvest can be a valuable component of an IWM strategy (Table 3). Currently, Australian farmers are not satisfied with the machinery aspects of this technique and substantial further innovation is required before the practice will be widely adopted.

Table 3. Effect of seed catching and removal at harvest on the next season's initial *L. rigidum* seedbank (from Powles and Matthews, 1996).

| | *L. rigidum* seed/$m^2$ | |
|---|---|---|
| Crop species | With seed catching | Without seed catching |
| | Seeds | Seeds |
| Peas | 1810 | 5215 |
| Barley | 346 | 577 |
| Wheat | 627 | 1290 |

Continued herbicide use

a) *Judicious herbicide rotation.* Despite the array of individual herbicides marketed and the large number of distinct chemistries, there is only a limited number of distinct herbicide modes of action. For example, the chemically distinct sulfonylurea, imidazolinone and triazolopyrimidine herbicides constitute 20% of the global herbicide market and yet all have the same mode of action (inhibit acetolactate synthase). Herbicide users must be able to easily identify the mode of action in order to rotate between different modes of action as part of IWM. Equally, when weed species develop target-enzyme-based resistance they frequently exhibit target site resistance across many herbicide chemistries which share the same mode of action (Devine and Shimabukuro, 1994, Saari *et al* 1994). Therefore, for herbicide users to judiciously rotate herbicides they need to be able to readily identify distinct herbicide modes of action. Yet, from the plethora of herbicide products available and from current labelling practices and marketing strategies it is difficult for farmers to discriminate between products versus modes of action. To overcome this problem a mandatory mode of action labelling system has now been instituted in Australia. All herbicide labels in Australia now carry a large alphabetical symbol identifying the herbicide mode of action. With this mandatory labelling system enabling easy identification and record of herbicide modes of action, rotation between herbicides, and herbicide mixtures, can be a very valuable component of IWM systems.

b) *Innovative herbicide use.* It must be emphasised that herbicides remain an integral part of IWM systems for continued cropping in the presence of multiple herbicide resistant *L. rigidum.* Selective herbicides which remain effective on resistant biotypes (eg trifluralin), or any new mode of action herbicides will be widely employed as the method of choice by farmers. Knock-down herbicides glyphosate or paraquat are used before crop seeding and in pasture years to limit grass weed seed production (pasture-topping) at the end of the growing season. A new technique, specifically to stop seed production of grass weeds in-crop, is the application of low rates of paraquat very late in the growing season. Table 4 shows that this technique, called crop-topping, can very effective in decimating *L. rigidum* seedset in pulse crops without effecting crop yield.

Table 4. *L. rigidum* seed bank following crop-topping with paraquat in pea crops for two seasons (from Powles and Matthews, 1996).

| | *L. rigidum* seeds ($m^{-2}$) | |
|---|---|---|
| | Crop-topping | No crop-topping |
| 1994 | 186 | 1021 |
| 1995 | 217 | 883 |

c) *Role of transgenic herbicide resistant crops.* A major change in herbicide technology is the introduction to world agriculture of transgenic crops which express a gene conferring resistance to herbicides (reviewed by Duke, 1997). Transgenic crops resistant to the broad-spectrum herbicides glyphosate or glufosinate are being widely adopted in North America (Duke, 1997). Similarly, for southern Australia, transgenic glyphosate and glufosinate resistant canola, and glufosinate resistant lupins will become available to growers (Bowran *et al*, 1997). The introduction of glyphosate or glufosinate transgenic herbicide resistant crops represent the introduction of two herbicide modes of action that have not previously been used for selective, in-crop weed control. Therefore, they represent further diversity in the herbicide modes of action available for rotation. Such transgenic crops, providing they are not over-used, will form a valuable part of IWM systems.

## CONCLUSIONS

As outlined above, multiple resistance to a wide range of herbicide chemistries in *L. rigidum* is a threat to the productivity and sustainability of cropping systems in Australian agriculture. However, the advent of multiple resistance has also had a beneficial impact in that it has forced the adoption of IWM strategies which work and are cost-effective. Grower experience, and the research summarised in this contribution, show that multiple herbicide resistant *L. rigidum* can be managed within cropping systems. The most far-reaching change required for successful management involves a change in attitude by growers and those that advise them. There has to be the acceptance that herbicides alone are not a sustainable weed management strategy and that IWM techniques must be adopted. Successful operators have changed their focus from a pre-occupation with herbicidal control to a focus on population dynamics in managing a weed population through periods of crop and/or pasture rotation. Herbicides remain a central plank of IWM strategies for the management of multiple resistant *L. rigidum* but there is increased cognisance of its potent biological/evolutionary capacity to overcome single control methods. Successful IWM strategies utilise herbicides and a range of non-chemical control methods which suit the cropping system, the weed spectrum and the economic and physical environment. Weed species, including *L. rigidum*, are not eradicated in such IWM systems but can be maintained at densities below tolerable economic loss levels. It is the experience of some researchers, advisers and farmers that the changes to farming systems (IWM) which have been forced by the appearance of multiple herbicide resistance have resulted in more sustainable and even more profitable farming systems than prevailed before resistance developed!

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# THE TECHNICAL AND FINANCIAL IMPACT OF HERBICIDE RESISTANT BLACK-GRASS (*ALOPECURUS MYOSUROIDES*) ON INDIVIDUAL FARM BUSINESSES IN ENGLAND

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## ABSTRACT

The costs of controlling black-grass, which has developed resistance to selective herbicides in cereals through enhanced metabolism, in continuous winter wheat have been calculated by developing a model based on farmer experience. This demonstrates that the financial implications of resistance, expressed as a reduction in net financial margins, are very sensitive to both crop yield and cereal price. The cost-effectiveness of a strategy to prevent or delay the development resistance was also studied. This suggests that avoiding very early sowing and adopting annual ploughing may result in a short term increase in costs but may provide the basis for the more economically sustainable production of continuous autumn sown crops on heavy land.

## INTRODUCTION

Black-grass (*Alopecurus myosuroides*) infests approximately 700,000 hectares of winter sown crops in England. Herbicide resistance in this weed was first confirmed in 1982. As a result of enhanced metabolism, severe problems of control in the field with all effective selective herbicides in cereals were recorded on two farms at Peldon, on the Essex coast, in 1984 (Moss & Cussans, 1985). There are now over 750 farms in Southern and Eastern England which have black-grass resistance to herbicides. The most common resistance mechanism is enhanced metabolism but target site resistance to aryloxyphenoxypropionate and cyclohexanedione herbicides has also been detected. Most of the instances of enhanced metabolism demonstrate varying degrees of cross-resistance to many selective cereal herbicides and are classified as moderately resistant, having not yet developed the level of resistance recorded at Peldon. This form of resistance develops slowly, at least to the herbicides which do not belong to the aryloxyphenoxypropionate and cyclohexanedione groups. The continued use of affected herbicides can give worthwhile control without greatly increasing the degree of resistance from one year to the next (Moss & Clarke, 1995).

Both the farms at Peldon practised continuous winter wheat production for at least twenty years prior to 1984, using shallow tillage after straw burning. In addition, sowing dates had been brought forward to September rather than the traditional time of mid-October. These management practices resulted in very high populations of black-grass and sequences of herbicides were eventually adopted to contain the weed. The development of the enhanced metabolism mechanism of resistance has been attributed partially to the high selection pressure by intensive herbicide treatment.

Despite persisting with the production of continuous autumn sown wheat, the level of resistance to herbicides has not increased greatly at Peldon since 1984, suggesting that a maximum degree of enhanced metabolism may have been reached. By the early 1990s, the farmers had adopted an integrated approach to minimise the impact of resistance. This involved annual ploughing and sowing in the latter half of October (Clarke & Moss, 1991). Economic optimum sowing dates are prior to mid-October and this delay in sowing not only involves yield losses but also an increased risk of not being able to establish all the crop area in the autumn and/or the danger of damage to soil structure.

## METHODS

The two farmers at Peldon were interviewed about how they modified their farm system to manage the weed whilst continuing to produce continuous winter wheat. This monoculture produces the highest margins for this soil type and location, even when sowing is delayed to the latter half of October. Using the data which resulted from these discussions, the additional costs of herbicide resistance in black-grass through enhanced metabolism were calculated. The variation in costs between the systems was restricted to cultivations, herbicides for black-grass control and their application and yield losses due to later times of sowing. Cultivation costs were based on published information (Nix, 1996) and herbicide costs were based on typical on-farm prices for the 1997 harvest.

The modification of the cropping systems, to minimise the impact of the developing resistance in black-grass, was split into six stages to enable the costs to be calculated:

Stage 1 - optimum economic system of early-sown crops established by non-plough tillage, single application of a full dose of a selective herbicide.
Stage 2 - multiple herbicide applications introduced.
Stage 3 - rotational ploughing (ploughing one in three years) introduced.
Stage 4 - ploughing every year introduced.
Stage 5 - delayed sowing introduced.
Stage 6 - spring cropping introduced.

Peldon is located in one of the driest areas of England (average annual rainfall of approximately 525 mm) and the sowing date in the latter half of October may not be achieved reliably in other parts of the country. Hence a stage 6 has also been added where some spring cropping occurs due to wet autumn conditions. The physical implications of each of these stages, according to farm experience, are described in Table 1.

The actual experiences of farmers were different in three respects to the process described above and in Table 1:

a) The moves from one stage to the other in this study were determined by yield losses due to weed competition and increased costs of herbicides. In practice, lack of information resulted in higher herbicide use and weed competition before changes in cultivations were adopted.

b) Straw burning was banned in the UK in 1992. The original system at Peldon was based on straw burning and two light cultivations prior to sowing. Deeper cultivation is now required to incorporate the straw and the costs of such cultivations were used in this study.
c) New herbicides have been introduced since 1984. While their efficacy on black-grass is reduced by enhanced metabolism, the herbicide policies used in this exercise were based on the farmers' experience of the current range of commercially available herbicides.

The additional costs of a 'sustainable system', which avoids or delays the development of resistance, were then estimated and compared to the costs of managing herbicide resistant black-grass once it is fully developed. Field experience by ADAS suggests that annual ploughing, sowing a significant proportion of the winter wheat in early-October and applying a single dose of a herbicide for the selective control of black-grass can be defined as the 'sustainable system' of producing continuous winter wheat. It is assumed that there would be a yield penalty of 2% compared with sowing from mid-September to early October. Typical growing costs were used (Nix, 1996) and the area payment was that made to English growers for the 1997 harvest. It is also assumed, in all the scenarios, that the development of target site resistance is avoided by minimising the reliance on aryloxyphenoxypropionate and cyclohexanedione herbicides.

Table 1. The stages of modification from the most economic system of growing continuous winter wheat in order to minimise the impact of developing herbicide resistance.

| | Resistance status of black-grass | Selective black-grass herbicides; full doses | Primary cultivation | Start of sowing | Yield loss[1] |
|---|---|---|---|---|---|
| Stage 1 | No resistance | 1 herbicide | Non-plough[2] | mid-Sept. | 0 % |
| Stage 2 | Developing | 3 herbicides | Non-plough[2] | mid-Sept. | 0-3% |
| Stage 3 | Developing | 3 herbicides | Rot. plough[3] | mid-Sept. | 0-5% |
| Stage 4 | Developing | 3 herbicides | Plough only[3] | mid-Sept. | 0-5% |
| Stage 5 | Developed | 3 herbicides | Plough only[3] | mid-Oct. | 7% |
| Stage 6[4] | Developed | 3 herbicides[5] | Plough only[3] | mid-Oct. | 7%[5] |
| | | 2 herbicides[6] | | | 25%[6] |

1. compared with yield of winter wheat sown between mid-September and early-October, without competition from black-grass. No yield losses occur at the beginning of Stages 2, 3 and 4 but they eventually occur as a result of a build up in black-grass populations, prompting a change in husbandry. Yield losses in stage 5 are due to later sowing, including a reduction in the quality of the soil structure.
2. cultivate three times, sow and roll.
3. rot. plough = rotationally plough one in three years. The cultivations associated with ploughing are plough, press twice, roll twice, pressure harrow twice on one third then sow and roll. Headlands are power harrowed.
4. a move from continuous winter wheat to 75% of the area in winter wheat and 25% of the area in spring wheat.
5. in the winter wheat
6. in the spring wheat

Hence, two baselines were used for comparative purposes:

- the optimum economic system of non-plough tillage and a single application of a selective herbicide (Table 2)
- a sustainable system of ploughing every year, sowing a significant proportion of winter wheat in early-October and a single application of a selective herbicide (Tables 3 & 4)

## RESULTS

Table 2 indicates financial penalties of resistance. Stage 1 was at one time a realistic system but is not now an option on many fields. Single applications of a herbicide used to result in very effective control of black-grass. Experiments done by ADAS in the early 1970s indicated an average of 99% control of black-grass heads from an early post-emergence (of crop and weed) application of 2,500 g/ha isoproturon. However, this level of control is not achieved in similar experiments some twenty five years later. This suggests that in many black-grass populations there may have been some increased metabolism of cereal herbicides.

Table 2. The additional cost at the different stages of modification of the farming system to minimise the impact of developing herbicide resistance, compared with non-plough tillage every year and one full dose of a herbicide (referred to as Stage 1 in Table 1).

| | Additional cost compared to Stage 1 (£/ha)[1] | |
|---|---|---|
| | Yield 8.0 t/ha | Yield 10.0 t/ha |
| Stage 2 | 38 - 62 | 38 - 68 |
| Stage 3 | 79 - 119 | 79 - 129 |
| Stage 4 | 124 - 164 | 124 - 174 |
| Stage 5 | 180 | 194 |
| Stage 6 | 193 | 216 |

1. where a range of values is given, the lower is without yield loss due to black-grass and the higher is where, over time, populations develop and cause a yield loss, prompting further changes in husbandry. Value of wheat (for calculation of value of yield loss) is assumed to be £100/t

It is clear that the adoption of the 'sustainable system' of annual ploughing and sowing a significant proportion of wheat in early-October increases costs when compared to non-plough tillage but is a better long-term option if it prevents the full expression of resistance (Table 3).

The values in Tables 2 and 3 assume a wheat price of £100/t. The price received by farmers has fluctuated over the last three years from below £80/t to above £130/t. Table 4 shows the reduction in net margins/ha (the margin over all costs, including a notional rent and interest charges) of having to adopt annual ploughing and late sowing to contain herbicide resistance in black-grass in continuous winter wheat, when compared with the 'sustainable' system of annual ploughing and sowing a significant proportion of wheat in early-October to prevent or delay the development of resistance. Reductions in margins are very sensitive to both crop yield and price and a significant negative net margin is likely to occur as a result of resistance at the lowest yield and price considered.

Table 3. The additional cost or (cost saving) at the different stages of modification of the farming system to minimise the impact of developing herbicide resistance, compared with the 'sustainable system' of annual ploughing and sowing a significant proportion of wheat in early-October to prevent its development

| | Additional cost compared to the sustainable system (£/ha) (1) | |
|---|---|---|
| | Yield 8.0 t/ha | Yield 10.0 t/ha |
| Stage 1 | (88) | (92) |
| Stage 2 | (50) - (26) | (54) - (24) |
| Stage 3 | (9) - 31 | (13) - 37 |
| Stage 4 | 36 - 76 | 32 - 82 |
| Stage 5 | 92 | 102 |

1. where a range of values is given, the lower is without yield loss due to black-grass and the higher is where, over time, populations develop and cause a yield loss, prompting further changes in husbandry. Value of wheat (for calculation of value of yield loss) is assumed to be £100/t. Additional costs of Stage 6 were not calculated.

Table 4. Net margins/ha (including area payments) of the sustainable system[1] according to yield and price of wheat and % reduction in these net margins due to the additional costs[2] necessary to manage resistance when it is fully developed (referred to as Stage 5)

| Yield | Price of wheat (£/t) | | | | | |
|---|---|---|---|---|---|---|
| | £70 | £80 | £90 | £100 | £110 | £120 |
| 7.0 t/ha | £-13 (597%) | £56 (143%) | £124 (67%) | £193 (45%) | £262 (35%) | £330 (28%) |
| 8.0 t/ha | £56 (143%) | £134 (63%) | £213 (41%) | £291 (32%) | £369 (26%) | £448 (22%) |
| 9.0 t/ha | £124 (67%) | £213 (41%) | £301 (31%) | £389 (25%) | £477 (21%) | £565 (19%) |
| 10.0 t/ha | £193 (45%) | £291 (32%) | £389 (25%) | £487 (21%) | £585 (18%) | £683 (16%) |

1. Annual ploughing, sowing a significant proportion of wheat in early-October and using a single herbicide to control black-grass.
2. Additional herbicide costs and yield losses due to late sowing.

The financial penalties as a result of herbicide resistance in black-grass could be more significant if farmers on heavy land had to sow crops in the spring as an additional cultural control measure. However, the experience of the farmers at Peldon suggests that this is unlikely in that area of England, where sowing of wheat can be reliably achieved in the latter half of October.

## DISCUSSION

This study suggests that, with continuous autumn cropping and using the current range of selective herbicides, annual ploughing and sowing a significant proportion of winter wheat in early-October will not maximise margins in the short term. However, if this approach continues to prevent or delay the development of resistance, it will be a more sustainable system. There are two major issues which prevent the practical adoption of this approach.

- it is not known if all field populations of black-grass have the propensity to develop resistance. Close monitoring will give an early-warning of enhanced metabolism, which develops slowly to herbicides which do not belong to aryloxyphenoxypropionate and cyclohexanedione groups.
- farmers are averse to risk and they will be inclined to sow winter wheat as soon as conditions allow, from early-September onwards. Experience in many of the areas infested with black-grass suggests that delaying the start of sowing until the last week in September provides the opportunity to achieve close to optimum yields on heavy soils, with no impact on machinery costs. Where farmers are unwilling to delay sowing, they need to consider whether they should be attempting to grow continuous early-sown autumn crops on fields infested with black-grass.

The recent reductions in the price of cereals in the UK and the prospect of lower intervention prices in the EU make it more important than ever to avoid the full expression of the enhanced metabolism form of herbicide resistance in black-grass. Whilst farmers may be tempted to adopt non-plough tillage in response to lower financial returns, they need also to consider the implications of the full expression of this type of resistance in such market conditions, particularly where yields are low.

## ACKNOWLEDGEMENTS

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# HRAC CLASSIFICATION OF HERBICIDES ACCORDING TO MODE OF ACTION

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## ABSTRACT

The Herbicide Resistance Action Committee (HRAC) has developed a system to classify herbicides by a letter code according to their modes of action. The system itself is not based on weed resistance risk assessment but can be used by the farmer or advisor as a tool to choose herbicides in different mode of action groups, so that mixtures, sequences or rotations of active ingredients can be planned.

## INTRODUCTION

Weeds interfere with crop plants by decreasing yields and causing other detrimental effects. Weed control, either by cultural or by chemical methods, is therefore an essential measure in crop protection. Herbicides play an important role in weed control in many crops. However, there is an increasing number of herbicide-resistant weed biotypes (Powles & Holtum, 1994; Heap, 1997). Many weeds have evolved resistance towards herbicides like triazines, acetolactate synthase- or acetyl CoA carboxylase-inhibitors due to mutated target sites. Additionally, in recent years grass weed species, e. g. *Lolium rigidum* and *Alopecurus myosuroides* have been identified with multiple resistance towards herbicides from different mode of action groups (Burnet *et al.*, 1994; Moss, 1992).

One component of a strategy to prevent the occurrence of herbicide resistance in weeds is the use of herbicides with different modes of action in mixtures, sequences or rotations (Jutsum & Graham, 1995). This is because the chances of a weed becoming simultaneously resistant to several herbicides are low, albeit exceptions may occur as in the cases of multiple resistance.

There are literally hundreds of herbicidally active compounds known or currently used worldwide (Tomlin, 1994). However, these act by a relatively limited number of modes of action (Devine *et al.*, 1993).

Information on modes of action is available for most herbicides, but is contained in a wide range of different publications. These are not necessarily readily accessible to those requiring this information for advisory purposes. In addition, there may be disagreement over the precise mode of action of a herbicide.

Thus, a concise classification of herbicides according to mode of action groups is required. HRAC has produced such a classification in order to achieve a global standardisation. In the preparation of the classification, scientists from the HRAC member companies (Table 1) as well as from universities and research institutes and from the WSSA (Weed Science Society of America) have been involved.

Table 1. Herbicide Resistance Action Committee (HRAC)

| Member Companies |
|---|
| AgrEvo |
| American Cyanamid |
| BASF |
| Bayer |
| Dow Elanco |
| DuPont |
| FMC |
| Monsanto |
| Novartis |
| Rhone-Poulenc |
| Tomen |
| Zeneca |

## CLASSIFICATION OF HERBICIDES

The herbicides are classified using a series of letter codes according to their modes of action but, where necessary, placed in sub-categories depending on chemical classes or similarity of symptoms.

If different herbicide groups share the same mode or site of action only one letter is used. In the case of photosynthesis inhibitors subclasses C1, C2 and C3 indicate different binding behaviour at the binding protein D1, or different classes. Bleaching can be caused by different mechanisms. Accordingly subgroups F1, F2 and F3 are used. Growth inhibition can be induced in different ways by herbicides from subgroups K1, K2 and K3.

Herbicides with unknown modes or sites of action are classified in group Z as 'unknown' until they can be grouped exactly.

In order to avoid confusion with I and O categories the letters J and Q are omitted.

Most of the herbicides currently used worldwide are covered by the system. New herbicides will be classified in the respective groups or in new groups (R, S, T...).

The system was in part developed in cooperation with the 'Weed Science Society of America' (WSSA). For reference the numerical system of the WSSA (Retzinger & Mallory-Smith, 1997) is listed, too. After intensive discussions within HRAC and regional working groups an alphabetical system was preferred by HRAC. The groups A, B and C are similar to an Australian classification system.

The aim of HRAC is to create a standardised classification of herbicides according to mode of action acceptable for use in as many countries as possible.

## USE OF THE HERBICIDE CLASSIFICATION SYSTEM

One factor important to the success of using herbicides effectively in combating resistant weeds or in preventing the occurrence of resistance is the knowledge of the mode of action of the respective herbicides. The herbicide user must be able to identify appropriate herbicides by their mode of action, e. g. on the label of the product. HRAC therefore developed a system to classify herbicides accordingly.

The classification system itself can only be used as a guide since there are cases where a weed population may be resistant to one herbicide in a grouping but not to others in that same group. However, the general principles of using combinations of herbicides with different modes of action for the prevention of resistance are still valid. There are also examples of weeds being resistant to more than one herbicide mode of action group. These are usually based on increased metabolism of herbicides (or physical processes such as reduced penetration). The use of combinations of herbicides with different modes of action may not help to prevent this type of resistance unless the combinations include herbicides that are detoxified in the plant via different routes (Wrubel & Gressel, 1994).

The HRAC herbicide classification in itself is not a resistance management document but is a useful tool that can be used to help in the design of resistance prevention strategies, which should be based not only on herbicide use but should include cultural and other practices that minimise the risk of weed resistance development.

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# HRAC: Herbicide classification

| HRAC Group | Mode of Action | Chemical Family | Active Ingredient | WSSA Group |
|---|---|---|---|---|
| A | Inhibition of acetyl CoA carboxylase (ACCase) | Aryloxyphenoxy-propionates 'FOPs' | clodinafop-propargyl<br>cyhalofop-butyl<br>diclofop-methyl<br>fenoxaprop-P-ethyl<br>fluazifop-P-butyl<br>haloxyfop-R-methyl<br>propaquizafop<br>quizalofop-P-ethyl | 1 |
| | | Cyclohexanediones 'DIMs' | alloxydim<br>butroxydim<br>clethodim<br>cycloxydim<br>sethoxydim<br>tralkoxydim | |
| B | Inhibition of acetolactate synthase ALS (acetohydroxyacid synthase AHAS) | Sulfonylureas | amidosulfuron<br>azimsulfuron<br>bensulfuron-methyl<br>chlorimuron-ethyl<br>chlorsulfuron<br>cinosulfuron<br>cyclosulfamuron<br>ethametsulfuron-methyl<br>ethoxysulfuron<br>fenpyrsulfuron<br>flazasulfuron<br>flupyrsulfuron<br>halosulfuron-methyl<br>imazosulfuron<br>metsulfuron-methyl<br>nicosulfuron<br>oxasulfuron<br>primisulfuron-methyl<br>prosulfuron<br>pyrazosulfuron-ethyl<br>rimsulfuron<br>sulfometuron-methyl<br>sulfosulfuron<br>thifensulfuron-methyl<br>triasulfuron<br>tribenuron-methyl<br>triflusulfuron-methyl | 2 |
| | | Imidazolinones | imazameth<br>imazamethabenz-methyl<br>imazamox<br>imazapyr<br>imazaquin<br>imazethapyr | |
| | | Triazolopyrimidines | cloransulam-methyl<br>diclosulam<br>flumetsulam<br>metosulam | |
| | | Pyrimidinylthiobenzo-ates | bispyribac<br>pyribenzoxim<br>pyrithiobac-Na<br>pyriminobac-methyl | |

# HRAC: Herbicide classification

| HRAC Group | Mode of Action | Chemical Family | Active Ingredient | WSSA Group |
|---|---|---|---|---|
| **C1** | Inhibition of photosynthesis at photosystem II | Triazines | ametryne<br>atrazine<br>cyanazine<br>desmetryne<br>prometryne<br>propazine<br>simazine<br>terbumeton<br>terbuthylazine<br>terbutryne | **5** |
| | | Triazinones | hexazinone<br>metamitron<br>metribuzin | |
| | | Uracils | bromacil<br>lenacil<br>terbacil | |
| | | Pyridazinones | pyrazon = chloridazon | |
| | | Phenyl-carbamates | desmedipham<br>phenmedipham | |
| **C2** | Inhibition of photosynthesis at photosystem II | Ureas | chlorobromuron<br>chlorotoluron<br>chloroxuron<br>dimefuron<br>diuron<br>ethidimuron<br>fluometuron (see F3)<br>isoproturon<br>linuron<br>methabenzthiazuron<br>metobromuron<br>metoxuron<br>monolinuron<br>neburon<br>tebuthiuron | **7** |
| | | Amides | propanil | |
| **C3** | Inhibition of photosynthesis at photosystem II | Nitriles | bromoxynil<br>(also group M)<br>ioxynil (also group M) | **6** |
| | | Benzothiadiazoles | bentazon | |
| | | Phenyl-pyridazines | pyridate | |
| **D** | Photosystem-I-electron diversion | Bipyridyliums | diquat<br>paraquat | **22** |
| **E** | Inhibition of protoporphyrinogen oxidase (PPO) | Diphenylethers | acifluorfen-Na<br>aclonifen<br>bifenox<br>fluoroglycofen-ethyl<br>fomesafen<br>halosafen<br>lactofen<br>oxyfluorfen | **14** |

# HRAC: Herbicide classification

| HRAC Group | Mode of Action | Chemical Family | Active Ingredient | WSSA Group |
|---|---|---|---|---|
| E | Inhibition of protoporphyrinogen oxidase (PPO) (continued) | Phenylpyrazoles | isopropazol<br>pyraflufen-ethyl | 14 |
| | | N-phenylphthalimides | flumioxazin<br>flumiclorac-pentyl | |
| | | Thiadiazoles | fluthiacet-methyl<br>thidiazimin | |
| | | Oxadiazoles | oxadiazon<br>oxadiargyl | |
| | | Triazolinones | carfentrazone-ethyl<br>sulfentrazone | |
| | | Triazolopyridinones | azafenidin | |
| F1 | Bleaching:<br>Inhibition of carotenoid biosynthesis at the phytoene desaturase step (PDS) | Pyridazinones | norflurazon | 12 |
| | | Nicotinanilides | diflufenican | |
| | | Others | fluridone<br>flurochloridone<br>flurtamone | |
| F2 | Bleaching:<br>Inhibition of 4-hydroxyphenyl-pyruvate-dioxygenase (4-HPPD) | Triketones | sulcotrione | 28 |
| | | Isoxazoles | isoxaflutole | |
| | | Pyrazoles | pyrazolynate<br>pyrazoxyfen | |
| F3 | Bleaching:<br>Inhibition of carotenoid biosynthesis (unknown target) | Triazoles | amitrole | 11 |
| | | Isoxazolidinones | clomazone | 13 |
| | | Ureas | fluometuron (see C2) | |
| G | Inhibition of EPSP synthase | Glycines | glyphosate<br>sulfosate | 9 |
| H | Inhibition of glutamine synthetase | Phosphinic acids | glufosinate-ammonium<br>bialaphos = bilanaphos | 10 |
| I | Inhibition of DHP (dihydropteroate) synthase | Carbamates | asulam | 18 |
| K1 | Microtubule assembly inhibition | Dinitroanilines | benefin = benfluralin<br>ethalfluralin<br>oryzalin<br>pendimethalin<br>trifluralin | 3 |
| | | Phosphoroamidates | amiprophos-methyl<br>butamiphos | |
| | | Pyridazines | dithiopyr<br>thiazopyr | |

# HRAC: Herbicide classification

| HRAC Group | Mode of Action | Chemical Family | Active Ingredient | WSSA Group |
|---|---|---|---|---|
| K1 | Microtubule assembly inhibition (continued) | Benzoic acids | DCPA = chlorthal-dimethyl | 3 |
| K2 | Inhibition of mitosis / microtubule organisation | Carbamates | chlorpropham<br>propham | 23 |
| K3 | Inhibition of cell division | Chloroacetamides | acetochlor<br>alachlor<br>butachlor<br>dimethachlor<br>dimethanamid<br>metazachlor<br>metolachlor<br>pretilachlor<br>propachlor<br>propisochlor | 15 |
| | | Carbamates | carbetamide | |
| | | Acetamides | diphenamid<br>napropamide | |
| | | Benzamides | propyzamide = pronamide<br>tebutam | |
| | | Oxyacetamides | mefenacet<br>fluthiamide | |
| | | Tetrazolinones | fentrazamide | |
| | | Others | cafenstrole | |
| L | Inhibition of cell wall (cellulose) synthesis | Nitriles | dichlobenil<br>chlorthiamid | 20 |
| | | Benzamides | isoxaben | 21 |
| M | Uncoupling (Membrane disruption) | Dinitrophenols | DNOC<br>dinoseb<br>dinoterb | 24 |
| N | Inhibition of lipid synthesis - not ACCase inhibition | Thiocarbamates | butylate<br>cycloate<br>dimepiperate<br>EPTC<br>esprocarb<br>molinate<br>orbencarb<br>pebulate<br>prosulfocarb<br>thiobencarb = benthiocarb<br>triallate<br>vernolate | 8 |
| | | Phosphorodithioates | bensulide | |
| | | Benzofuranes | ethofumesate | |
| | | Chloro-Carbonic-acids | TCA<br>dalapon | 26 |

# HRAC: Herbicide classification

| HRAC Group | Mode of Action | Chemical Family | Active Ingredient | WSSA Group |
|---|---|---|---|---|
| O | Action like indole acetic acid (synthetic auxins) | Phenoxy-carboxylic-acids | 2,4-D<br>2,4-DB<br>dichlorprop = 2,4-DP<br>MCPA<br>MCPB<br>mecoprop = MCPP = CMPP | 4 |
| | | Benzoic acids | dicamba | |
| | | Pyridine carboxylic acids | clopyralid<br>fluroxypyr<br>picloram<br>triclopyr | |
| | | Quinoline carboxylic acids | quinclorac<br>(also group Z)<br>quinmerac | |
| | | Others | benazolin-ethyl | |
| P | Inhibition of indoleacetic acid action | Phthalamates | naptalam | 19 |
| | | Semicarbazones | diflufenzopyr-Na | |
| R | ... | ... | ... | |
| S | ... | ... | ... | |
| . | ... | ... | ... | |
| Z | Unknown | Arylaminopropionic acids | flamprop-methyl /-isopropyl | 25 |
| | | Benzylethers | difenzoquat | 8 |
| | | Organoarsenicals | DSMA<br>MSMA | 17 |
| | | Others | bromobutide<br>(chloro)-flurenol<br>cinmethylin<br>cumyluron<br>dazomet<br>dymron = daimuron<br>flupoxam<br>metam<br>pelargonic acid | 27 |

# QUANTIFICATION OF THE DEVELOPMENT OF HERBICIDE-RESISTANT BLACK-GRASS) (*ALOPECURUS MYOSUROIDES)* UNDER HERBICIDE-BASED RESISTANCE MANAGEMENT REGIMES.

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## ABSTRACT

Field and glasshouse studies have been conducted since 1990 to examine the sustainability of the use of a mixture and sequence of herbicides with contrasting modes of action and mechanisms of degradation, as a herbicide-based resistance management strategy. The in-field performance of the repeated use of such a strategy and its impact on resistance development within a population of *Alopecurus myosuroides* has been evaluated. Evaluation of the resistance status of survivors of the herbicide treatments between 1993 and 1996 revealed a statistically significant increase in resistance where a single herbicide was used annually. Where the annual application was of a mixture / sequence, no significant increase in resistance was recorded. It is concluded that the integration of cultural and agronomic control methods into such a herbicide-based management strategy can provide a sustainable approach to the management and prevention of *A. myosuroides* resistance development.

## INTRODUCTION

For the registration of a new active ingredient, or re-registration of an existing active ingredient in Europe, it is necessary to address the potential for the development of resistance and where necessary detail a resistance prevention or management strategy.

Given the need to maintain an abundant, varied and high quality food supply to an increasing population it is inevitable that for the foreseeable future weed control will be herbicide based and that resistance prevention or management strategies must also be herbicide based, although incorporating good agronomic practices.

Various strategies have been proposed for resistance prevention or management by expert groups, e.g. The Weed Resistance Action Group (Moss & Clarke 1994) - Guidelines for the prevention and control of herbicide-resistant black-grass (*Alopecurus myosuroides*), and commercial organisations, e.g. Novartis Crop Protection (1995) - Black-grass control the total approach. The core of such strategies is the integration of herbicide use with non-chemical methods of weed population reduction such as; cultivations, drilling date modifications, crop rotation and the use of stale seed beds / stubble clean-up. Although there is considerable commonality in the strategies, there are differences with respect to the advised intensity of herbicide use, the types of herbicides to be employed, the value of mixtures and sequences of herbicides and the sustainability of herbicide-based programmes.

*A. myosuroides* is an intensively competitive weed with cereal crops where uncontrolled populations have been found to reduce yield potential by up to 45%, (Moss, 1987). *A. myosuroides* biotypes resistant to chlorotoluron were first identified by Moss & Cussans, (1985) and by 1992, Clarke, Blair & Moss (1994) had detected resistance to fenoxaprop-ethyl on 90 farms after just three years of usage in the UK.

The continuing study reported here addresses the sustainability of a resistance prevention and management strategy through the evaluation of both in-field control of *A myosuroides*, and biotype resistance status following yearly use of a strategy based on clodinafop-propargyl, an aryloxyphenoxypropionate herbicide.

The study was initiated in autumn 1992 to investigate the effects of repeated applications of herbicide treatments on *A. myosuroides* resistance development, in order to test management strategies, (Mills & Ryan, 1995). The *A. myosuroides* had been confirmed as resistant to chlorotoluron, isoproturon (phenylureas), and fenoxaprop-ethyl (aryloxyphenoxypropionate). Chlorotoluron had been used for many years on the farm in conjunction with minimal cultivations and intensive cereal cropping. Cross resistance to other herbicides was suspected as the first field usage of fenoxaprop-ethyl in 1990 resulted in unsatisfactory control. Results from an initial field trial in 1991/2 and a glasshouse study of survivors confirmed resistance to isoproturon and fenoxaprop-ethyl and showed a level of resistance to clodinafop-propargyl. However, mixtures and sequences based on clodinafop-propargyl performed very well.

## MATERIALS AND METHODS

### Field Study

The trial was unreplicated with a plot size of 1440 $m^2$, the same treatments being re-applied to the same plots each year with a commercial sprayer at 200 l/ha. The growth stage at application of the *A. myosuroides* ranged from GS13 to 24. Herbicides were the commercially available formulations: clodinafop-propargyl 'Topik 240EC' + additive, fenoxaprop-P-ethyl 'Cheetah Super' or fenoxaprop-ethyl 'Cheetah R', clodinafop-propargyl + trifluralin 'Hawk' + additive, triallate 'Avadex BW Granular', and isoproturon 'Hytane 500SC'. The additive employed was a 97% mineral oil 'Actipron' or 'Adder', see Table 1 for the use rates employed. *A. myosuroides* control in the field plots was assessed by visual evaluation compared to untreated plots supplemented by headcounts.

### Glasshouse Study

Seed was collected from surviving plants in each plot during July, except for the sequence/mixture treatment in harvest 1995 where there were too few surviving plants. The glasshouse determination of herbicide resistance was based on the methodology of Clarke, Blair & Moss (1994). Seeds, including that collected from Rothamsted and Peldon - the standard sensitive and resistant biotypes, were germinated on filter paper soaked in 0.2% potassium nitrate solution. After germination the seeds were transplanted into pots containing sterile loam, (five plants per pot and five pots per treatment) and grown under glasshouse conditions to the three leaf stage. Herbicides were applied using a Novartis precision plot sprayer fitted with Lurmark 02-F110 nozzles calibrated to deliver 200 l/ha at a spray pressure of 200 kPa. Clodinafop-propargyl as Topik was applied at six doses: 7.5, 15, 22.5, 30, 45 and 60 g.ai/ha plus 1l/ha mineral oil. Herbicidal efficacy was determined by fresh weight evaluation 5 weeks after application.

## RESULTS

### Field Study

The data (Table 1) are presented in the form of head counts to reveal the treatment effects on population levels during the five years. In the untreated plot the population of *A. myosuroides* has increased over the five years up to a very high level in the 1997 season.
*A. myosuroides* control with clodinafop-propargyl + additive alone was expected to be low initially and fall rapidly year on year due to the confirmed resistance status. However, for the first four years of annual applications the control of *A. myosuroides* was little changed. *A. myosuroides* population density in the this plot remained relatively stable up to four years, however, in the fifth year survival was much higher.
Control with fenoxaprop-P-ethyl has been low from the start of the study, as expected from previous commercial experience in this field. Resistance to fenoxaprop is high in this biotype and the population has continued to increase in this treated block over the five years.
Results for isoproturon have been variable during the study reflecting the greater impact of environmental conditions on the efficacy of this compound. A very high *A. myosuroides* population has now built up in this block, similar to that of the untreated area.

Table 1. *A myosuroides* head counts in harvest years 1993-1997 ( heads/m$^2$).

| Treatment | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|
| Untreated | 300 | 544 | 1146 | 1861 | 4524 |
| Clodinafop-propargyl + mineral oil: 30g +1l/ha | 108 | 162 | 72 | 137 | 812 |
| Fenoxaprop-P-ethyl: 69g/ha | 240 | 344 | 1136 | 966 | 4824 |
| Isoproturon: 2500g/ha | 204 | 138 | 1016 | 1707 | 3316 |
| Triallate pre-emergence followed by clodinafop-propargyl + trifluralin + mineral oil: 2250, 30 + 958g + 1l/ha | 28 | 14 | 1 | 10 | 12 |

Triallate followed by clodinafop-propargyl + trifluralin has consistently been the best treatment in each of the five years. The high level of activity has been maintained even after repeated application over the five year period. The population of *A. myosuroides* in this plot has remained very low as a result of the herbicide treatment, despite there being a small number of survivors each year. The contribution of the triallate and trifluralin has been sufficient to prevent the control break-down which occurred with clodinafop alone.

Glasshouse Study

This study tested seed samples from the clodinafop-propargyl, triallate followed by clodinafop-propargyl + trifluralin and untreated plots, Peldon and Rothamsted biotypes populations were included as standard resistant and sensitive biotypes.

The data were analysed by calculation of the $ED_{50}$ from the dose-percentage response curves for each treatment and year, (Table 2). Statistical analysis on these data were performed by one-way ANOVA followed by Bodeferroni's modified *t*-test, a test which reduces the significant value of $p$ to account for significant differences that may occur by chance in the course of multiple comparisons. The results of these comparisons are presented below.

Table 2. Analysis of $ED_{50}$ (g ai/ha). Comparison between years for each treatment

| Year | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|
| Treatment | Mean and standard error | | | |
| Untreated | 6.64 +/- 0.56 | 6.78 +/- 1.28 | 5.19 +/- 0.28 | 5.37 +/- 0.76 |
| Clodinafop-propargyl + mineral oil: 30g +1l/ha | 5.75 +/- 0.47 | 9.46 +/- 0.97 | 7.68 +/- 0.98 | 12.4 +/- 2.29* |
| Triallate pre-emergence followed by clodinafop-propargyl + trifluralin + mineral oil: 2250, 30 + 958g + 1l/ha | 7.09 +/- 1.14 | 8.97 +/- 1.21 | ** | 11.3 +/- 1.04 |

*Significant at p = 0.001042. ** Complete control, no plants available for seed collection

All groups and years analysed within a single ANOVA: D.F. = 1250. F = 4.4507
$p = 0.000082$ . Modified t-test (Bodeferroni's), critical value for 48 comparisons = 0.001042

The untreated populations sampled each year fall between the resistant and sensitive standards in terms of their susceptibility to clodinafop-propargyl. The untreated appears to become slightly less resistant as the years progress, possibly due to the increasing population size available to sample and dilution of the resistant individuals in the absence of selection pressure from herbicides.

There was a significant increase in resistance in the survivors of the clodinafop-propargyl treatment in 1996 (mean 12.40 +/- 2.29) compared to 1993 (mean 5.75 +/- 0.47) with $p$ = 0.000124 suggesting that resistance increased with prolonged treatment. This effect was not apparent in either the untreated group or with the triallate followed by clodinafop-propargyl + trifluralin; 1996 mean of 11.30 +/- 1.04 and 1993 mean of 7.09 +/- 1.14 with $p = 0.016327$.

This trial was designed to maximise selection pressure from the herbicide treatments. Non-chemical methods of delaying or controlling resistance such as crop rotation, ploughing, use of stale seed beds and non-selective herbicides were deliberately excluded. In this extreme situation the sequence/mixture continued to provide excellent control in the field and in parallel no statistically significant increase in resistance of surviving plants.

## DISCUSSION

Glasshouse evaluation of the survivors of the herbicide treatments over the years has revealed a statistically significant increase in resistance between 1993 to 1996 with the clodinafop-propargyl repeated treatment. This was expected due to the selection pressure exerted by the use of a single mode of action/mechanism of degradation in a resistant population and in the absence of any non-chemical control methods. Surprisingly, however, the decline in field performance has been less rapid than was expected. Studies over future years will evaluate the kinetics of any further decline in performance.

The resistance status of survivors from the triallate followed by clodinafop-propargyl + trifluralin sequence has not changed in a statistically significant manner. Even in the absence of supportive non-chemical control measures this treatment has remained effective and the population of blackgrass in this plot is at a very low level compared to that present prior to initiation of the trial (Mills & Ryan 1995). Future year's field testing will seek to determine the period of time for which this herbicide approach remains sustainable both with and without non-chemical support methods. It does appear, however, that the use of sequences/mixtures of herbicides with different modes of action and mechanisms of degradation ( Hatzios 1991, Kreuz *et al* 1991) can form an effective resistance management strategy, the incorporation of non-chemical methods may result in a sustainable strategy in all circumstances.

This study utilised an *A. myosuroides* population which was resistant to one of the chemical classes (aryloxyphenoxypropionate) included in the resistance management strategy and highlights the differences in resistance between members of the same chemical class where the resistance is herbicide degradation based. This has important implications for the development of resistance management/prevention strategies, suggesting that approaches to resistance management should be individual herbicide rather than chemical class based.
The inadequate efficacy of fenoxaprop-ethyl in the first year of use in the field where this study was conducted, indicates that the *A. myosuroides* population was already resistant to a degree even though there had been no history of sustained or even regular fop herbicide use. There had, however, been a history of intensive phenylurea herbicide use which had resulted in the selection of biotypes with the capacity for enhanced herbicide degradation and thus cross-resistance to a previously unused chemical class. It may be that rapid in-field herbicide degradation based resistance development ascribed to aryloxyphenoxypropionate herbicides may be a function of previous, non-chemical class related herbicide use rather than an inherent feature of this chemical class.

The development of herbicide-based resistance management/prevention strategies and the assessment of their sustainability must be addressed by evaluation of: the history of the target species in displaying resistance, resistance mechanisms pre-existing from previous herbicide use and the susceptibility of new herbicides to these pre-existing mechanisms. It was on this basis that the strategy described in this paper was developed, that is: limited resistance to trifluralin or triallate, the difference in resistance susceptibility between clodinafop-propargyl and other aryloxyphenoxypropionate herbicides, and the utilisation of herbicides with different modes of action and mechanisms of degradation.

Resistance is a global problem which is most amenable to local solutions, although certain principles such as those described above are universal. The least successful solutions are likely to be generalised strategies based on broad herbicide groupings or the restriction of herbicide use, both of which fail to accommodate the complexities of individual herbicide/target interactions.

The field performance of the herbicide component of the Novartis blackgrass resistance management strategy has been excellent over the years of the study. Even in the absence of the recommended cultural control measures, the levels of control achieved in the field have remained commercially acceptable and sustainable. Variations on this strategy for the control of herbicide-resistant *Avena* spp. and *Lolium* spp. are under development.

## ACKNOWLEDGEMENTS

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# DISTRIBUTION AND MANAGEMENT OF TRIAZINE-RESISTANT WEEDS IN THE MID-ATLANTIC REGION OF THE U. S. A.

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## ABSTRACT

Since 1972, five weeds growing in the mid-Atlantic region of the U. S. A. have been documented as being resistant to the triazine herbicides. Populations of triazine-resistant smooth pigweed (*Amaranthus hybridus)* and common lambsquarters (*Chenopodium album*) are now widespread throughout the region, while the spread of triazine-resistant barnyardgrass (*Echinochloa crus-galli*), giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti*) has been minimal. A number of factors account for the development and spread of these weeds, particularly the lack of crop and herbicide rotation and the spreading of manure containing weed seed on clean farmland. A number of management programmes are in place to help farmers battle these pernicious weeds. The use of sequential herbicide applications utilizing pre-emergence and post-emergence herbicides coupled with rotations of herbicides with contrasting modes of action are an essential component of these integrated control strategies.

## INTRODUCTION

As of 1996, there were 183 documented herbicide-resistant weed biotypes reported worldwide (Heap, 1996). Of these 183 cases, 60 weed species had evolved resistance to the triazine herbicides, representing the most common and widespread form of resistance.

In the U. S. A., the first reported case of a weed resistant to the triazine herbicides was reported in the mid-1960's (Ryan, 1970). Since then, 14 other weeds have been reported as being resistant to the triazine herbicides in the U. S. A. (Heap, 1996).

In the mid-Atlantic region of the U. S. A., the first reported case of triazine-resistance occurred in 1972 (LeBaron, 1982). Since then, four other weeds have been documented as being resistant to the triazine herbicides (Ritter, 1989).

## THE MID-ATLANTIC REGION OF THE U. S.

The mid-Atlantic region of the U. S. A. includes the states of New Jersey, Pennsylvania, Maryland, Delaware, West Virginia and Virginia. While agriculture in this region is rather diverse, approximately 70% of the farmed acreage is devoted to row crop agriculture. Maize and soya beans are the primary crops grown with cereals, forages, sorghum, vegetables and tobacco being secondary crops. Many of the farms located throughout the central section of this region, typically called the Piedmont, are dairy farms. It is common throughout the Piedmont for maize to be grown every year without rotation to other crops. Maize is cut and stored late summer as silage to provide feed for cows during the year. Any weed seed harvested with the maize will be spread back on farmland in manure.

Earlier surveys conducted through the region indicated that the triazine herbicides were the mainstay of herbicide applications in maize. The use of atrazine plus simazine, or cyanazine plus atrazine, was commonplace. These combinations are relatively inexpensive, safe to the crop and do a good job in controlling both grass and broadleaf weeds. Unfortunately, the continued use of these herbicides, coupled with the lack of crop rotation, lack of control of surviving weeds, and spreading of weed seed in manure fostered the development and spread of triazine-resistant weeds.

Triazine-resistant weeds in the region

In 1972, smooth pigweed (*Amaranthus hybridus*) was the first weed documented as being resistant to the triazine herbicides in the mid-Atlantic region (LeBaron, 1982). Since then, barnyardgrass (*Echinochloa crus-galli*) (1978), common lambsquarters (*Chenopodium album*) (1984), velvetleaf (*Abutilon theophrasti*) (1984) and giant foxtail (*Setaria faberi*) (1984) have also been documented as being resistant to the triazine herbicides (Ritter, 1989).

Many of these weeds were identified and continue to spread primarily in the Piedmont area of this region. Some of the associated factors responsible for the development and spread of these weeds are listed in Table 1.

Table 1. Factors influencing the spread of triazine-resistant weeds in the mid-Atlantic region of the U. S. A.

1. Lack of crop rotation
2. Lack of herbicide rotation with continued use of triazine herbicides
3. No-till/minimum-till farming
4. Lack of control of weeds which survived pre-emergence herbicide treatment(s)
5. Spread of weed seed, especially through manure

As of 1997, triazine-resistant smooth pigweed and common lambsquarters are common throughout much of the mid-Atlantic region. Barnyardgrass was located on two different farms in Carroll Co. Maryland in 1978, but has not spread beyond those sites. Velvetleaf was identified on one farm in Carroll Co. Maryland in 1984, and has slowly spread throughout neighbouring farms. Giant foxtail was identified on one farm in Harford Co. Maryland in 1984, and has spread to neighbouring farms as well.

Management of triazine-resistant weeds in the region

A number of factors are important in the management of triazine-resistant weeds. Some of these are listed in their order of discussion in Table 2.

Table 2. Factors to consider in the management of triazine-resistant weeds in the mid-Atlantic region of the U. S. A.

1. Crop rotation
2. Herbicide rotation and selection
3. Identify triazine-resistant species
4. Avoid movement of triazine-resistant weed seed
5. Tillage
6. Control weed escapes

Crop rotation and herbicide selection are two key factors that farmers need to consider. Unfortunately, on many dairy farms, crop rotation does not occur. Maize is grown continuously and generally utilized as silage for the herd. Forages may be planted on the farm as well, but are only rotated with maize every 6 to 7 years. In general, grass or cereal crops are not part of this rotation.

Farmers rely heavily upon the use of herbicides to control weeds. A good understanding of herbicide mode of action is required. Switching between triazine and urea herbicides will not control triazine-resistant weeds. We have seen cross-resistance with common lambsquarters and smooth pigweed between the triazines and ureas. Neither atrazine (triazine herbicide) nor linuron (urea herbicide) provide effective control of triazine-resistant smooth pigweed and common lambsquarters in maize. Because of the lack of good pre-emergence herbicides, many of the triazine-resistant weed escapes have to be controlled with post-emergence herbicides.

No-till and minimum-till farming are practiced quite heavily in this region. The Piedmont is rather hilly, and cultivation of weed escapes is not a common practice. Erosion is a problem. Good no-till cultivators are not available. The soil in many parts of this area have large rock outcrops where cultivation would be difficult. Thus, reliance on post-emergence herbicides to control weeds surviving pre-emergence herbicide applications is essential in order to prevent them from producing new seed.

Rain is critical in activating soil applied pre-emergence herbicides. If sufficient rain does not occur to activate these herbicides, weeds may still germinate. When weed escapes occur, it is unknown whether they are herbicide-resistant species or not. This is critical in determining one's choice of a post-emergence herbicide. Kits are available that can be used in the field to determine whether or not an emerged weed is resistant to the triazine herbicides and aid in the decision-making process in selecting a proper post-emergence herbicide (Anon., 1997).

It is recommended that the spreading of manure containing triazine-resistant weed seed be confined to areas of the farm already infested with such plants. Combines should also be cleaned of weed seed when moving from infested areas to non-infected areas.

Tillage can play a role in the management of triazine-resistant weeds. Table 3 outlines data the authors generated in the 1980's exploring different herbicide and tillage systems (Ritter et al., 1985).

Table 3. Effects of tillage practices on control of triazine-resistant smooth pigweed in maize*.

| Tillage method | ----------------Smooth pigweed control---------------- 4 wk | 10 wk | 18 wk |
|---|---|---|---|
| | ----------------------------(%)---------------------------- | | |
| Mouldboard plough + disc | 88 | 85 | 72 |
| Chisel plow + disc | 80 | 77 | 63 |
| Disc twice | 77 | 77 | 64 |
| No-till in maize stalks | 55 | 63 | 44 |
| No-till in rye cover | 56 | 52 | 31 |

*Used with permission and adapted from Ritter et al., 1985, *Weed Science* 33:400-404. Data averaged across two tillage times (autumn and spring), four herbicide programmes and two years. Visual ratings made at 4, 10 and 18 weeks after pre-emergence herbicide applications. Numbers represent percent smooth pigweed control based on a visual scale of 0 to 100 with 0 = no control, 100 = complete control, as compared to an untreated herbicide area (0 % control).

In the case of tillage, better smooth pigweed control was obtained where more aggressive tillage was performed (mouldboard plough + disc, chisel plow + disc and disc twice) in comparison to no-tillage practices (no-till in maize stalks or no-till in rye cover).

A number of herbicides have been evaluated by the authors to aid farmers in the management of triazine-resistant weeds. While the following table is not complete, it gives farmers an idea of which family of compounds to consider in their battle against triazine-resistant weeds.

Table 4. Herbicides that can help in the management of triazine- resistant weeds in maize.

| Herbicide family | Annual grasses | Common lambsquarters | Smooth pigweed | Velvetleaf |
|---|---|---|---|---|
| Amide-types | Yes | No | Partial | No |
| Aryloxyphenoxy-propionates + Cyclohexanediones | Yes | No | No | No |
| Benzoic + phenoxy acids | No | Yes | Yes | Yes |
| Dinitroanalines | Yes | Partial | Partial | Partial |
| Imidazolinones | Yes | Partial | Yes | Partial |
| Nitriles | No | Yes | No | Yes |
| Sulfonylureas | Yes | Yes | Yes | Yes |
| Thiocarbamates | Yes | Partial | Yes | No |
| Triazines | No | No | No | No |
| Ureas | No | No | No | No |

Over the past few years, the authors have been investigating a number of new pre-emergence and post-emergence herbicides for the control of triazine-resistant common lambsquarters in maize. Currently, this weed is the most widespread triazine-resistant weed in the mid-Atlantic region. Very few pre-emergence herbicides are available for control of this weed. A common pre-emergence herbicide combination utilized throughout the region consists of a tank-mix of metolachlor + atrazine + pendimethalin. Lately, the pre-emergence use of flumetsulam has shown promise in the control of this weed. Pre-emergence use of halosulfuron also shows promise. Post-emergence use of dicamba is the mainstay in control of triazine-resistant common lambsquarters throughout the region. The use of low rates of dicamba in combination with primisulfuron has provided good control as well. Table 5 outlines data collected by the authors regarding control of triazine-resistant common lambsquarters in no-till maize (Ritter and Menbere, 1993 - 1995).

Table 5. Control of triazine-resistant common lambsquarters in no-till maize 1993 - 1995*.

| Treatment | Applied | Rate | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|
| | | (kg/ha) | --------------------(%)------------------ | | |
| Atrazine + simazine | Pre | 1.68 + 1.68 | 3 | 0 | 0 |
| Metolachlor + flumetsulam | Pre | 2.41 | 98 | 90 | 98 |
| Metolachlor + halosulfuron | Pre | 2.00 + 0.073 | 93 | 85 | 98 |
| Metolachlor halosulfuron | Pre | 2.00 + 0.084 | 98 | 95 | 98 |
| Metolachlor + atrazine + pendimethalin | Pre | 4.48 + 1.68 | 50 | 32 | 30 |
| Dicamba | EP | 0.56 | 100 | 97 | 100 |
| Primisulfuron + dicamba | EP | 0.021 + 0.14 | 95 | 93 | 100 |

*Data represent visual ratings of common lambsquarters control made late in the growing season. Rating scale is from 0 - 100 with 0 = no control and 100 = complete control.

Data from Table 5 indicate almost complete lack of control of triazine-resistant common lambsquarters provided by atrazine + simazine. A commonly used pre-emergence combination consisting of metolachlor + atrazine + pendimethalin averaged 30 - 50 % control late in the growing season. Newer mixtures such as metolachlor + flumetsulam or metolachlor + halosulfuron provided 85 % control or better, late season. Excellent post-emergence control of triazine-resistant common lambsquarters was provided by dicamba or combinations of dicamba + primisulfuron.

In conclusion, five different weeds are documented as being resistant to the triazine herbicides in the mid-Atlantic region of the U. S. A. A number of factors account for their development and spread, especially the lack of crop rotation and herbicide rotation coupled with the spreading of manure containing triazine-resistant weed seed back on farmland.

Management of these weeds needs to take into consideration several variables including crop and herbicide rotation, herbicide selection, identification of herbicide-resistant weed species, tillage, control of weed escapes, and avoiding weed seed dispersal to clean farmland.

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# SESSION 10C

# CROPPING PRACTICES AND BIRDS

Session Organiser DR N W SOTHERTON
*The Game Conservancy Trust, Fordingbridge, UK*

Poster Papers 10C-1 to 10C-8

# AVAILABILITY OF WEED SEEDS AND WASTE CEREALS TO BIRDS ON ARABLE FIELDS DURING SPRING

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## ABSTRACT

There is increasing concern and evidence that modern agricultural practices have reduced the availability of weed seeds and waste cereal grains on arable fields during the winter. However, we believe that early spring may be another bottleneck for food availability for granivorous birds. During March 1996 and 1997 we collected nearly 300 0.25m$^2$ by 1cm deep soil samples from arable and set-aside fields on 16 sites across southern and eastern England to assess availability of seeds to birds. Total seed numbers varied by site ($P<0.001$), year ($P<0.002$) and crop type ($P=0.067$). Set-aside contained more seeds than winter or spring tilled fields. Waste grain densities were low in all field types and were found in only 7.8% of samples. Our data suggest that the seed bank available in arable fields during spring is insufficient to maintain adequate food resources for pheasants and other granivorous birds, but that set-aside, although extremely variable, might help mitigate these problems if managed carefully.

## INTRODUCTION

Several seed-eating farmland bird species have suffered significant declines in numbers during the last 30 years (Tucker & Heath, 1994, Campbell *et al*., 1997). Reduced availability of weed seeds and cereal grains during winter has been cited as a probable cause of these declines (Stoate, 1996, Campbell *et al*., 1997). Several important changes in land use and practice have caused this reduction in seed availability. These include the switch from spring to autumn-sown cropping, increased herbicide inputs and use of more efficient machinery resulting in less overwinter stubble, fewer broadleaved weeds and less grain spilt during harvest (Wilson *et al*., 1995, O'Connor & Shrubb, 1986). We hypothesised that availability of seeds and grains during spring for nesting granivorous birds such as pheasants, (*Phasianus colchicus*), may be another dietary 'bottleneck' as nutrient requirements increase above maintenance levels prior to the breeding season (Wise, 1994).

During incubation, opportunity for feeding is reduced; to compensate birds utilise existing fat reserves. Draycott *et al.* (in press) demonstrated in a field experiment that spring fat reserves of hen pheasants could be maintained at their winter levels by continuing supplementary feeding wheat grain into April. Hen pheasants which were fed into spring produced twice as many nesting attempts, were seven times more likely to re-nest and hatched three times as many chicks compared to pheasants which were not provided with supplementary grain and were foraging solely on natural foods. Faecal analysis of samples collected from the above study revealed very low levels of grain or wild seed in the diet of pheasants foraging on an unsupplemented diet compared to the diet of birds provided with supplementary grain (Hoodless *et al.,* in press). This contrasts to a number of studies in the USA and Europe where cereals are important components in the spring diet of pheasants, (Trautman, 1952, Korschgen, 1964, Pullianen, 1966, Stromborg, 1979).

We hypothesize that reduced seed and grain availability in spring may impact the condition of pheasants and other granivorous farmland bird species and may be an important factor influencing the breeding success of a number of declining farmland birds. This study aimed to determine the availability of weed seeds and spilt grains to farmland birds in spring.

## MATERIALS AND METHODS

We collected soil samples from arable fields on 16 farming estates in southern and eastern England in March 1996 and 1997. On average 10 samples were collected from each site in each year. Sampling involved randomly throwing a $0.25m^2$ quadrat within 20 m of the field boundary which is the area most often used by feeding pheasants, (Hoodless *et al*., in press) and scraping the top 1 cm of soil and seed bearing vegetation into a plastic bag (Klute *et al*., 1997).

Samples were sieved through a 1 mm diameter mesh. Large stones and plant materials were removed from the soil to aid sieving. Soil was then washed through the sieve until most of the soil particles and seeds <1mm in diameter had been removed. We disregarded seeds <1mm in diameter as pheasants rarely take seeds this small (R A H Draycott, unpubl. data). The remaining seeds and small pieces of debris were then placed into a labelled white container and allowed to air dry before examination.

The contents of each container were spread thinly on a petri dish marked with a grid of 5mm x 5mm squares and then examined systematically under a binocular microscope (10-40x magnification). All seeds were identified where possible, with the aid of 'The Seed Identification Handbook' (NIAB 1986). For this analysis total seed number and numbers of *Chenopodium spp*., *Polygonum spp*. and cereal grain numbers were calculated per sample.

Data were analysed using general linear model ANOVA with site, year and crop type as independent variables. All data were $\log_{10}$ transformed to normalise data distribution.

## RESULTS

There was considerable variation in seed numbers between sites (Figure 1), crop types (Figure 2) and fields. Site and year were the most important factors in determining variation in total seed number, (Site: 15df, $F$=6.26, $P$=0.000. Year: 1df, $F$=9.99, $P$=0.002. Crop type: 2df, $F$=2.73, $P$=0.067). Set-aside fields contained the greatest numbers of seeds, but the differences were not significant due to large variation between sites and fields.

The most commonly occuring seeds were *Chenopodium spp.* seeds (present in 48.2% of samples) and *Polygonum spp.* seeds (present in 41.5% of samples). Site and year were the most important factors in determining the numbers of *Chenopodium spp.* (Site: 15df, $F$=6.30, $P$=0.000. Year: 1df, $F$=5.68, $P$ =0.018. Crop type: 2df, $F$=1.54, $P$=0.216) and *Polygonum spp.* seeds (Site: 15df, $F$=3.48, $P$=0.000. Year: 1df, $F$= 23.56, $P$=0.000. Crop type: 1df, $F$=1.13, $P$=0.289). Cereal grains were found in only 7.8% of samples. Site was the most important factor in determining the variation in numbers of cereal grains, (15df, $F$= 1.91, $P$=0.02). Year and crop type were not significant (Year: 1df, $F$=1.28, $P$=0.259, Crop type: 2df, $F$=2.60, $P$=0.076). There was a difference in the proportions of samples containing cereal grains between crop types (14df, $\chi^2$=27.33, $P$=0.017), (Figure 3).

Figure 1. Mean numbers of seeds and grains per site (mean of all fields on each site).

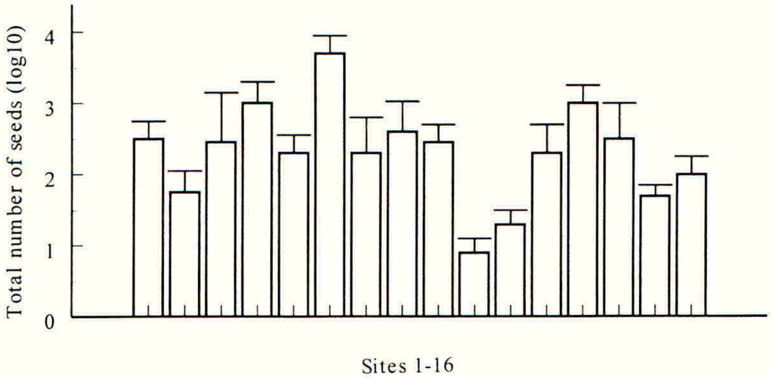



Figure 2. Mean number of seeds and grains in Set-aside, autumn sown and spring sown fields (all sites combined).

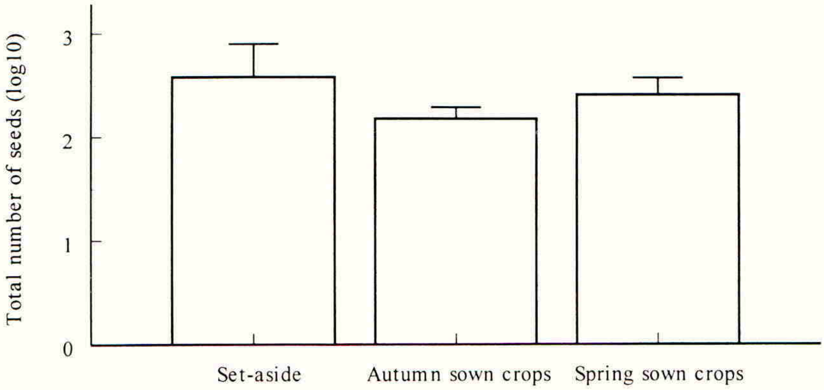
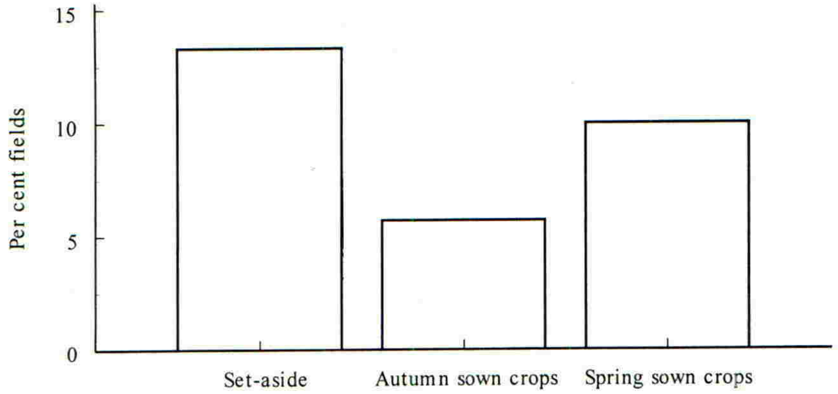


Figure 3. Proportion of fields of Set-aside (n=30), autumn sown crops (n=194) and spring sown crops (n=58) containing grain.




## DISCUSSION

Our results highlighted the low availability of natural grain and seeds on arable fields to farmland birds in spring. Set-aside fields contained more grains and wild seeds than autumn and spring tilled fields. However, there was considerable variation between set-aside fields and on many seed and grain numbers were very low. The large variation in the data was probably due to a number of interacting factors including soil type, previous crop type and crop management. All will influence seed numbers, but all are dependent on the other factors.

It is likely that numbers of grains and seeds on set-aside would be higher during the autumn and winter months, but the results from our study show that if this is true, these reserves are largely used up by March. *Chenopodium spp.* and *Polygonum spp.* were the most common weed seed species found on all field types. These species are present and in most cases important in the diet of many granivorous birds including grey partridge (*Perdix perdix*), tree sparrow, (*Passer montanus*), greenfinch, (*Carduelis chloris*), red-legged partridge (*Alectoris rufa*), pheasant and bullfinch (*Pyrrhula pyrrhula*), (Campbell *et al.*, 1997). Wilson *et al.,* (1996) found that over-winter stubble was an important foraging habitat for many seed eating passerines, almost to the exclusion of other field types. Our data highlight the low availability of seed and grain in spring on many set-aside fields and the possible impact on body condition of birds in spring due to poor diet.

Lack (1992) reported that winter and spring tilled fields will generally only be a good source of seeds for a short period after cultivation. Most grains found on spring-sown crops were of recently sown barley. Spring sown barley is now relatively rare compared to 30 years ago (O'Connor & Shrubb, 1986). The combination of weedy overwinter stubbles followed by sowing of spring barley probably provided better foraging for pheasants and farmland passerines. This would also have been beneficial to *Polygonum spp.* which are spring germinating and favour spring cultivation.

The provision of wheat or similar grains via small feed hoppers in breeding territories of pheasants (principally along woodland edges and field margins) during spring can help mitigate these problems. Alternatively, feed mixes can be planted under the Wild Bird Cover option on set-aside. This would be particularly important on set-aside fields where species diversity is poor.

## ACKNOWLEDGEMENTS

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# THE EFFECTS OF HERBICIDE INPUT LEVEL AND ROTATION ON WINTER SEED AVAILABILITY FOR BIRDS

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## ABSTRACT

Causes of the decline in the numbers of farmland bird species are unknown, but for seed-eating species the availability of seed during the autumn and winter may be important. A study was carried out on selected plots of the TALISMAN experiment to assess the effects of different rotations and herbicide inputs on the seed bank and weed flora. Higher seed densities were recorded on different rotations at Boxworth and High Mowthorpe. Within rotations higher seed densities were recorded at lower herbicide rates. Weight of seeds did not correspond to differences in seed densities. Vegetation assessments at Boxworth and Drayton were generally higher on the alternative rotation and low herbicide inputs, but results were more variable at High Mowthorpe. These results are discussed in relation to the availability of food for birds during autumn and winter.

## INTRODUCTION

In the last 30 years there has been a decline in the numbers of many farmland bird species. The tree sparrow, reed bunting, linnet, skylark and corn bunting have all declined by more than 50% (Campbell *et al.*, 1997). This may be due to the indirect effects of increased pesticide application, but there are little data available to determine specific factors important in declining numbers. One potential reason for the decline is the low availability of seed during the autumn and winter.

TALISMAN (Towards a Lower Input System Minimising Agrochemicals and Nitrogen) was a MAFF-funded research project which examined the effects of reduced nitrogen and pesticide inputs over two simultaneous six year rotations. At harvest 1996, the rotation was complete and the cumulative effects of six years' reduced input levels were available for study. This provided an opportunity to examine the effects of different rotations and low herbicide rates on weed and seed densities and hence possible food availability for seed eating birds.

## MATERIALS AND METHODS

The experiment was carried out on selected plots of the TALISMAN experiment at three ADAS sites: Boxworth, Drayton and High Mowthorpe, in autumn 1996. Sampling compared the two rotations - standard (winter dominated cropping) and alternative (increased spring cropping), and compared full and reduced rates (generally up to 50% of full) of herbicide applications within each rotation. Crops harvested in 1996 were break crops which had been autumn and spring sown on the standard and alternative rotations respectively. At Boxworth there were two replicates in two blocks and at other sites one replicate in three blocks. All plots received full rates of nitrogen, fungicides and insecticides, appropriate to the rotation. For further details of cropping, pesticide and nitrogen inputs and effects on weeds, yields and profitability see Cook & Clarke (this volume).

The seed bank was sampled at Boxworth and High Mowthorpe after harvest. From each plot, 60 cores (2.5 cm diameter and 5 cm deep), were taken and bulked together. Three subsamples, representing 60% of the total weight were processed by extraction using a wet sieving and flotation technique (Roberts & Ricketts, 1979) and seeds identified to species. Two assessments of weed density were made at all three sites; after harvest in late August/early September and in late October/November. Fifteen quadrats (16 at Drayton) of 0.25 $m^2$ (0.1 $m^2$ at Boxworth on the alternative rotation for the first count) were sampled on each plot. Data were converted to counts $m^{-2}$ and analysis of variance was carried out on the two or three most common species and subsets of the square root transformed data. Weight of seeds was calculated using published seed weight data for individual species (Grime *et al.*, 1990), or by weighing 100 seeds from the Boxworth reference collection.

## RESULTS

### Seed bank

At Boxworth much higher densities were recorded on alternative rotation plots, the highest density being on the alternative rotation with low herbicide rates at nearly 27 000 $m^{-2}$ (SEM = 6 606), whereas at High Mowthorpe mean seed densities were very low on the alternative rotation (2 000 - 3 500 $m^{-2}$) but much higher on standard plots (13 000 - 18 000 $m^{-2}$). At both sites and all treatments, the seed bank was dominated by a few common species. At Boxworth there was a difference in the quantitative species composition between the rotations. On the standard rotation, *Alopecurus myosuroides*, *Galium aparine* and *Bromus commutatus* (species common on heavy soils dominated by winter cropping) were dominant, whereas on the alternative rotation, *Anagallis arvensis*, *Atriplex patula* and *Kickxia spuria* (spring germinators) were the most common. At High Mowthorpe, the three most common species were the same on standard and alternative rotations.

At Boxworth, analysis of *A. arvensis*, forbs and total seeds produced significant interactions (Table 1). Higher seed densities were recorded in the alternative than in the standard rotation. Although differences were large for some species/groups they were not significant. Where treatment differences were significant this was usually at the herbicide level, with higher seed densities at the lower rates of herbicide application. However, the design of the experiment at Boxworth with only two blocks, meant that differences between the rotations were unlikely to be statistically significant. There were no differences between treatments for *A. myosuroides* (and 'grasses' since this species was the major component of this group). However, because it was necessary to maintain *A. myosuroides* under control, full rates of isoproturon were applied to all treatments.

Seed densities were higher (although not significantly) in the standard rotation at High Mowthorpe (Table 1). This was surprising since *Papaver rhoeas* accounted for over half the total seed bank. This species is generally a summer annual and should, therefore, be favoured by the increased spring cropping in the alternative rotations Plant count data recorded in spring/summer 1996, indicated a high density of poppies in the standard rotation (Green, pers. comm.) and this species is a prolific seed producer.

Table 1. Mean seed bank densities and seed weight $m^{-2}$ (square root transformed; except seed weights) of different species and groups of species and total weight of seeds on each rotation and herbicide level at a) Boxworth and b) High Mowthorpe.

| a) Boxworth | Standard Rotation | | Alternative Rotation | | | |
|---|---|---|---|---|---|---|
| Herbicide | Full | Low | Full | Low | SEM(Int) | SEM(Treat) |
| *Anagallis arvensis* | **1.9** (3.6) | **6.5** (42.3) | **66.1** (4 369) | **127.7** (16 307) | 8.70* | 6.15**† |
| *Alopecurus myosuroides* | **24.8** (615) | **18.1** (328) | **20.6** (424) | **22.1** (488) | | |
| *Atriplex patula* | **1.9** (3.6) | **13.9** (193) | **38.8** (1 505) | **51.1** (2 611) | | |
| Total Grasses | **33.2** (1 102) | **24.0** (576) | **22.3** (497) | **24.7** (610) | | |
| Total Forbs | **24.2** (586) | **34.7** (1 204) | **91.0** (8 281) | **150.9** (22 771) | 8.65* | 6.12**† |
| Total | **47.0** (2 209) | **46.6** (2 172) | **97.3** (8 780) | **160.7** (25 824) | 9.04* | 6.39*† |
| Grass weight (mg) | **4 360** | **3 080** | **1 967** | **3 402** | | |
| Forb weight (mg) | **3 532** | **5 184** | **6 062** | **17 626** | | 1 704*† |
| Total weight (mg) | **23 756** | **14 539** | **14 597** | **25 566** | | |

| b) High Mowthorpe | Standard Rotation | | Alternative Rotation | | | |
|---|---|---|---|---|---|---|
| Herbicide | Full | Low | Full | Low | SEM(Int) | SEM(Treat) |
| *Papaver rhoeas* | **80.4** (6 464) | **111.8** (12 499) | **26.8** (718) | **45.7** (2 088) | | |
| *Stellaria media* | **39.1** (1 529) | **32.6** (1 063) | **10.4** (108) | **14.4** (207) | | |
| *Poa* spp. | **27.3** (745) | **23.7** (562) | **17.2** (296) | **10.5** (110) | | |
| Total Grasses | **29.8** (888) | **27.1** (734) | **17.6** (310) | **11.0** (121) | | |
| Total Forbs | **100.6** (10 120) | **122.9** (15 104) | **36.9** (1 362) | **53.6** (2 873) | | |
| Total | **106.3** (11 300) | **127.4** (16 231) | **42.0** (1 764) | **56.4** (3 181) | | |
| Grass weight (mg) | **313** | **438** | **65** | **35** | | |
| Forb weight (mg) | **3 656** | **4 849** | **1 467** | **2 130** | | |
| Total weight (mg) | **13 024** | **9 815** | **5 306** | **4 429** | | |

Transformed data are given with back-transformed means in parentheses. SEMs are given only when there is a significant difference between mean values. SEM (Int) gives the standard error of the interaction mean. For SEM (Treat) # denotes standard error of factor 1 (rotation) and † denotes standard error of factor 2 (herbicide level). * = $P < 0.05$: ** = $P < 0.01$: *** = $P < 0.001$

The relationship between treatment and seed weight was different to that for seed numbers. At Boxworth, total seed weight was similar on standard rotation full herbicide and alternative rotation low herbicide rates, despite the fact that these plots had the lowest and highest number of seeds respectively. There was a significant difference in forb weights between herbicide treatments. At High Mowthorpe, no differences were significant, but for all groups analysed, seed weights were higher on the standard rotation plots where higher densities were recorded.

Vegetation

Plant counts ranged from a mean of only seven plants $m^{-2}$ at Drayton on the standard rotation with full rate of herbicide (August), to over 300 plants $m^{-2}$ at Boxworth on the alternative rotation with low rates of herbicide (September). At Boxworth and Drayton, the most important species changed between plant counts after cultivations in autumn, whereas at High Mowthorpe, where no soil disturbance had taken place, the same species were dominant in August and October. Plant counts were generally higher in the alternative than in the standard rotation at the same herbicide level (particularly at Boxworth). At Drayton and High Mowthorpe the most important species were similar in both rotations although some spring germinating species were present in the alternative but not in the standard rotation. However at Boxworth, as with seed counts, *A. arvensis* and *K. spuria* were more important in the alternative than in the standard rotation.

Within rotations, counts were higher on plots with reduced herbicide inputs. For most groups/species analysed there were significant differences between treatment means at the rotation or herbicide level, although for some there was also a significant interaction (Table 2). At Boxworth, significant differences between treatments were recorded only for forb species/groups, whereas at Drayton, higher weed numbers were consistently recorded on low rate herbicide plots. For some species at High Mowthorpe, significantly higher populations were recorded on the standard rotation.

## DISCUSSION

Since previous cropping is likely to have a major effect on post harvest weed density, seed counts will more accurately reflect the cumulative effects of six years of treatment than autumn vegetation assessments. It would be necessary to examine vegetation following the full range of previous crops (especially cereals) in order to draw more firm conclusions about any cumulative effect on autumn/winter weed density than was possible in the present study.

It was not possible to identify appropriate treatments to maximise seed availability for birds, because seed numbers did not necessarily correspond to seed weight. However, different bird species feed on seeds of different plants. For example, in finches the size of the beak can determine the size of the seeds preferred (Newton, 1972). The number or weight of seeds available may therefore be a less meaningful measure of available resource than the species present. This study has shown that the change to spring cropping as well as changes in herbicide use can have an effect on the species composition in certain circumstances, which may therefore be a factor in the decline of seed eating bird species.

In this study, abundance of grasses generally showed a less consistent relationship with cropping regime or herbicide rates than did broad-leaved weeds. The more abundant broad-leaved species tended to occur at higher densities under the alternative rotation (e.g. *A.*

Table 2. Mean plant counts $m^{-2}$ (square root transformed) of individual species and groups of species at a) Boxworth, b) High Mowthorpe and c) Drayton on each sampling date

| a) Boxworth | Standard Rotation | | Alternative Rotation | | | |
|---|---|---|---|---|---|---|
| Herbicide | Full | Low | Full | Low | SEM(Int) | SEM(Treat) |
| *Atriplex patula* | **2.16** | **3.89** | **4.94** | **9.91** | 0.66* | 0.47**† |
| | (4.7) | (15.1) | (24.4) | (98.2) | | |
| *Anagallis arvensis* | **0.62** | **1.23** | **6.03** | **7.23** | | 0.09*# |
| | (0.4) | (1.5) | (36.4) | (52.3) | | |
| *Alopecurus myosuroides* | **1.75** | **1.44** | **6.79** | **4.33** | | |
| | (3.1) | (2.1) | (46.1) | (18.7) | | |
| Total Grasses | **2.21** | **2.15** | **7.05** | **4.43** | | |
| | (4.9) | (4.6) | (49.7) | (19.6) | | |
| Total Forbs | **3.27** | **4.78** | **8.64** | **14.59** | 0.54** | 0.31*# |
| | (10.7) | (22.8) | (74.6) | (212.9) | | 0.38***† |
| Total | **8.03** | **8.54** | **16.04** | **17.49** | | |
| | (64.5) | (72.9) | (257.3) | (305.9) | | |

| b) High Mowthorpe | Standard Rotation | | Alternative Rotation | | | |
|---|---|---|---|---|---|---|
| Herbicide | Full | Low | Full | Low | SEM(Int) | SEM(Treat) |
| *Lolium* spp. | **3.31** | **4.21** | **2.03** | **1.43** | 0.223* | 0.239*# |
| | (10.9) | (17.7) | (4.1) | (2.0) | | |
| *Stellaria media* | **0.00** | **0.17** | **0.90** | **5.25** | 0.745* | 0.233*# |
| | (0.0) | (<0.1) | (0.8) | (27.6) | | 0.527*† |
| Poa annua | **0.52** | **1.60** | **1.44** | **1.39** | | |
| | (0.3) | (2.6) | (2.1) | (1.9) | | |
| Total Grasses | **3.36** | **4.69** | **2.53** | **2.01** | 0.185** | 0.175*# |
| | (11.3) | (22.0) | (6.40) | (4.04) | | |
| Total Forbs | **0.56** | **2.17** | **1.93** | **6.80** | | 0.355*# |
| | (0.3) | (4.7) | (3.7) | (46.2) | | 0.419**† |
| Total | **5.13** | **5.53** | **4.04** | **7.24** | | 0.457*† |
| | (26.3) | (30.6) | (16.3) | (52.4) | | |

| c) Drayton | Standard Rotation | | Alternative Rotation | | | |
|---|---|---|---|---|---|---|
| Herbicide | Full | Low | Full | Low | SEM(Int) | SEM(Treat) |
| *Aethusa cynapium* | **1.55** | **2.96** | **2.51** | **4.46** | | 0.20**† |
| | (2.4) | (8.8) | (6.3) | (19.9) | | |
| *Atriplex patula* | **1.30** | **2.40** | **1.80** | **1.94** | 0.118* | 0.083*† |
| | (1.7) | (5.8) | (3.2) | (3.8) | | |
| Total Grasses | **0.00** | **0.17** | **0.33** | **2.35** | 0.290* | 0.111*# |
| | (0.0) | (<0.1) | (0.1) | (5.5) | | 0.205*† |
| Total Forbs | **2.33** | **4.05** | **3.41** | **5.56** | | 0.150***† |
| | (5.4) | (16.4) | (11.6) | (30.9) | | |
| Total | **2.55** | **4.15** | **3.96** | **6.63** | | 0.229*# |
| | (6.5) | (17.2) | (15.7) | (44.0) | | 0.221**† |

Transformed data are given with back-transformed means in parentheses. SEMs are given only when there is a significant difference between mean values. SEM (Int) gives the standard error of the interaction mean. For SEM (Treat) # denotes standard error of factor 1 (rotation) and † denotes standard error of factor 2 (herbicide level). * = $P < 0.05$: ** = $P < 0.01$: *** = $P < 0.001$

*arvensis*) and low herbicide regimes (e.g. *Stellaria media*). On a national basis, these include species which have shown evidence both for an increase and for decline over the past 30 years (Campbell *et al.*, 1997). Several of these species are known to occur, or are members of families which occur frequently in the diets of declining farmland bird species. It is noteworthy that *Galium aparine* and *P. rhoeas*, which are broad-leaved species which tended to show greater abundance under standard rotations in the study, are members of plant families which are not significant components of the diet of declining bird species (Campbell *et al.*, 1997).

Whilst there is some knowledge of the weed species preferred, there is little information available on the quantitative feeding requirements of farmland birds. At present it is not possible to predict whether increases in broad-leaved weed and weed seed density found in this study are likely to be of any value to declining farmland bird species. Since many of these species are known to have declined over the past 25 years (Campbell *et al.*, 1997), weed densities comparable to those found in the early 1970s are likely to represent the resource requirement needed to stabilise and reverse these declines. A closer analysis of the scattered information on weed density and species changes over the past 25 years and associated evidence from weed management regimes such as conservation headlands, would greatly assist our ability to determine the requirements for continued survival of farmland bird species. Further analysis of this nature, ideally supported by appropriate large-scale experimental studies, is needed before we are able to predict whether the manipulations in cropping regime and herbicide use of the TALISMAN study are able to deliver benefits for declining farmland bird species.

Cultivations carried out after harvest will reduce the density of seeds available to birds, because seed densities at depth will be lower than at the surface due to losses from the seed bank over time, and birds will only take seeds at the surface of the soil. This suggests that the loss of winter stubbles due to increased winter cropping is a likely contribution to the decline in birds which feed on arable weed species. To improve farmland for birds it is necessary to develop economically and agronomically acceptable farming practices which allow increased spring cropping. The recent proposals for winter stubbles, with reduced herbicide use, under the Arable Stewardship programme, should contribute towards such a mechanism.

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# SEASONAL CHANGES IN HABITAT USE BY YELLOWHAMMERS (*Emberiza citrinella*)

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## ABSTRACT

In summer, foraging Yellowhammers switched from broad-leaved crops to barley, and then to wheat, as the cereal crops ripened. However, Yellowhammers gathered invertebrates from both cropped and adjacent uncropped habitats, including sparsely vegetated set-aside managed as Wild Bird Cover. Cereal-based Wild Bird Cover was the most used foraging habitat relative to its availability in early winter. We suggest that the management of Wild Bird Cover on set-aside can contribute to the conservation of farmland buntings by increasing availability of invertebrates in summer and seed food in winter.

## INTRODUCTION

Many seed-eating birds associated with farmland habitats have declined in numbers in Britain and other parts of northern Europe (Gibbons *et al.*, 1996). Each of the four bunting species occurring on farmland in Britain has experienced a decline over this period, with Yellowhammer *Emberiza citrinella* being the most recently affected. The causes of bunting declines have been attributed to a number of factors associated with agricultural intensification. These include the loss of winter stubbles and livestock feed sites in arable areas as sources of winter food (Donald & Evans, 1994, Evans & Smith, 1994), and the loss of invertebrate food for nestlings, resulting from changes in farming practices (Evans *et al.*, 1997, Wilson & Browne, 1993, Aebischer & Ward, 1997, Stoate *et al.*, in press). Invertebrates favoured as nestling food by buntings are generally phytophagous. Modern farming practices, such as frequent use of herbicides in arable crops remove food plants of these invertebrates, reducing their availability to foraging birds (Sotherton, 1991). Herbicides are also thought to reduce the suitability of winter stubbles as a food source by removing seeding weeds.

Current environmental incentives to arable farmers provide for the creation of low-input crops for birds under the set-aside Wild Bird Cover option (WBC) and, from 1998, within a new pilot Arable Stewardship Scheme. Incentives are also available in some Environmentally Sensitive Areas (ESAs) for reduction and selectivity of herbicide and insecticide use on cereal headlands ('Conservation Headlands') (Sotherton, 1991). Such prescriptions create weedy, invertebrate-rich crops within conventionally managed arable systems and provide potential foraging habitats for buntings throughout the year. This study assesses seasonal changes in habitat use by Yellowhammers on an arable farm where potential foraging habitats include commercial crops, Wild Bird Cover planted on set-aside, and gamebird feed sites.

## METHODS

### The study area

The study site, The Loddington Estate in Leicestershire, is a 334ha mixed arable and livestock farm. The soils at Loddington are predominantly heavy clay and crops are mainly autumn-sown. Wheat, barley oilseed rape and field beans are grown on the main arable area, while 13% of the farm area is pasture. Woodland covers about 8% of the farm area.

Farm management at Loddington is strongly influenced by the ecological requirements of wild gamebirds. Set-aside (15% of arable area in 1995) is managed for gamebirds, a proportion of it being planted with spring-sown game crops, creating a mixture of growing crop and other sparse, low vegetation during the nesting season. This Wild Bird Cover takes two forms – kale-based and cereal (triticale) -based mixtures in 8m wide strips within 20 m wide set-aside strips. Perennial field margin vegetation (2m wide) is maintained as nesting cover for gamebirds and songbirds and as a hibernating habitat for invertebrate predators of crop pests. Herbicide and insecticide use is used selectively on the outer 6m of cereal crops (Conservation Headlands) to increase invertebrate abundance (Sotherton, 1991). In winter, grain is distributed by hand along some hedges and provided in hoppers at permanent feed sites to provide food for gamebirds.

### Foraging observations

During May and June, 1993 and 1995, Yellowhammer nests were located and observations of foraging flights made from each nest. A microphone positioned close to the nest enabled the observer, located 30 m away, to record every visit to the nest, even when returning birds were not seen. Observations lasted 1.5 – 2 hours and were carried out when nestlings were 4 – 10 days old. The number of foraging sorties recorded varied between five and fifteen per nest (mean ± se: 1993, 7.0 ± 0.57 (15 nests); 1995, 8.3 ± 0.53 (25 nests). Birds were not observed to visit more than one habitat per foraging sortie. Foraging locations were recorded on a map and distances were subsequently measured to estimate foraging ranges. The area available to foraging birds was assumed to be the area within a 300 m radius of the nest, this being the maximum distance travelled by foraging birds at this site and similar to that recorded in other studies of Yellowhammers in Switzerland by Biber (1993), and in Germany by Lille (1996). In 1995, foraging observations were conducted over a long enough period to allow the data to be divided into early (observed before 20 June) and late (after 20 June) observations.

The area of each habitat and the number of foraging visits to each habitat were expressed in proportions of the total habitat available within the foraging range for each nest. The proportional habitat use and availability sum to one over all habitats, so the proportional use or availability of any one habitat type is not linearly independent of the others. The data derived from foraging observations were therefore analysed using compositional analysis (Aitchison, 1986; Aebischer *et al.*, 1993). This technique overcomes the problem of the unit-sum constraint by transforming the proportions $x_i$ to logratios -

$\log(x_i/x_j)$ - where 'i' and 'j' are habitat types and j is fixed for the purpose of analysis. The hypothesis of random habitat use is equivalent to a multivariate test of equality (based on Wilk's lambda, $\Lambda$) between logratios corresponding to use and those corresponding to availability. The test does not depend on the choice of habitat j used as denominator.

If compositional analysis detects non-random habitat use, it then allows the habitat groups to be ranked according to their relative use as foraging habitats. In our rankings, '>' signs signify the order of ranking and a triple sign (>>>) represents significant differences between adjacent ranks at P<0.05. Therefore, a>b>>>c signifies that the relative use of habitats 'a' and 'b' was significantly higher than that of 'c' (at P = 0.05) but that the rankings of habitats 'a' and 'b' did not differ significantly. The following habitats were recognized: 'wheat', 'barley', 'broad-leaved crops' (oilseed rape, beans), 'field boundary', 'sparse vegetation' (tracks, set-aside) and 'other habitats' (pasture, woods).

In 1994 and 1995 the outer tramline of each cereal field was walked three times during June. Yellowhammers flushed from the Conservation Headland and from an area of equivalent width within the adjacent crop were recorded. Mean numbers observed in the outer Conservation Headland belt and inner conventionally managed belt were then compared using a paired t test on log-transformed data.

In the winter a 60ha section of the farm was walked seven times during November and December 1996, and seven times during February and March 1997. Every point within the defined section was visited to within 50 m. The number of Yellowhammers observed, and the habitat in which they were seen was recorded. The following habitat types were recognised: ‘cereal crop’, ‘oilseed rape crop’, kale-based WBC (‘kale’), cereal-based WBC (‘triticale’), ‘field boundary’ and ‘feed site’. The area of each habitat was measured from a map and compositional analysis was again used to assess the relative use of these habitats by foraging Yellowhammers in the two winter periods.

## RESULTS

### Summer

Birds did not forage at random in the available habitat in 1993 ($\Lambda$=0.003, $F_{5,10}$=595.25, $P$<0.001). The habitat ranking, in order of greatest to least relative use was:

barley>>>broad-leaved crop>sparse vegetation>>>field boundary>other>wheat

This relative habitat use for the 8 - 30 June period did not differ between 1993 and 1995 (Wilk’s lambda, $\Lambda$=0.492, $F_{5,7}$=1.44, n.s.). In 1995, habitat use in the early season differed from that in the late season ($\Lambda$=0.087, $F_{5,7}$=14.66, $P$=0.001); there was significant non-random habitat use from both early nests ($\Lambda$ =0.121, $F_{5,7}$=10.13, $P$=0.004) and late nests ($\Lambda$=0.154, $F_{5,8}$=8.80, $P$=0.004). Ranking the habitat types in the two periods revealed that wheat moved from last to second rank in terms of relative use:

2 - 20 June 1995:
broad-leaved crop>sparse vegetation>barley>>>field boundary>other>wheat

21 June - 6 July 1995:
barley>wheat>field boundary>broad-leaved crop>sparse vegetation>other

Although the mean number of yellowhammers flushed from Conservation Headlands (1.03 ± 0.35) was higher than that from adjacent conventionally managed crop belt (0.65 ± 0.19), this difference was not statistically significant ($t_{13}$ = 1.00, P= 0.33).

Winter

In winter, habitat use in the November/December period differed from that in the February/March period ($\Lambda$=0.028, $F_{5,7}$=49.18, $P$<0.001). There was significant non-random habitat use from both the early winter period ($\Lambda$<0.001, $F_{5,2}$=3347.05, $P$<0.001) and the late winter period ($\Lambda$<0.001, $F_{5,2}$=1958.83, $P$=0.001). Ranking the habitat types in the two periods revealed that triticale was used significantly more than other habitats in the early winter, and that significantly greater use was made of feed sites in late winter. Rape and cereal crops were used significantly less than all other habitats in both periods:

November/December 1996:
triticale>>>feed site>kale>field boundary>>>oilseed rape crop>cereal crop

February/March 1997:
feed site>>>field boundary>kale>triticale>>>oilseed rape crop>cereal crop

## DISCUSSION

Observations of Yellowhammers at Loddington suggest that foraging birds switch from broad-leaved crops to barley, and later to wheat as the breeding season progresses. We know that these birds were gathering both invertebrates and unripe cereal grains and that, of the invertebrates, Lepidoptera caterpillars were amongst the most used food items relative to their availability (Stoate *et al.*, in press). Phytophagous invertebrates such as caterpillars are most likely to be found in weedy crops (such as Conservation Headlands) and in field boundaries. However, we found that field boundaries were used relatively less than commercial crops and sparsely vegetated areas. The latter represent relatively open habitats where invertebrates such as tipulids and spiders, two groups known to be taken by foraging yellowhammers, can be gathered without obstruction from dense vegetation.

Cereal crops represent a source of grain as well as invertebrate food and this may explain their relatively high use over habitats such as field boundaries that support higher invertebrate densities. The temporal sequence in which crops were used supports this. Yellowhammers used barley, and then wheat, as these crops began to ripen. Polyphagous predatory invertebrates such as carabid beetles and spiders, known to be taken by yellowhammers (Stoate *et al.*, in press), disperse from field margins into the adjacent fully sprayed crop (Wratten & Thomas, 1990). Here they may be more available to forag31/07/97ing Yellowhammers because of the more open structure of the crop and this may account for the fact that there was not a greater difference in the use of these two habitats by foraging birds. However, proximity of hedges to Conservation Headlands may influence foraging behaviour. Reduced pesticide use in cereal headlands may therefore increase the availability of invertebrates to Yellowhammers by protecting those in field boundaries from spray drift (Longley *et al.*, 1997), and by supporting arable invertebrates within the headland which could then disperse into more open parts of the crop. The role of Conservation Headlands as a food source for breeding birds on farmland requires further investigation.

Breeding Yellowhammers at Loddington used sparsely vegetated tracks and spring-sown Wild Bird Cover crops as a foraging habitat significantly more, relative to their availability, than field boundaries, woods and pastures, and (before ripening) wheat. The short spring-sown Wild Bird Cover crop, and short grass at its edges, represents a source of invertebrate food, providing grain and other seeds only when nesting has ended.

In winter, commercial crops were not used by foraging Yellowhammers. 'Wild Bird Cover' planted with triticale, but not that planted with kale, was used relatively more in the early part of the winter. However, the use of this crop declined relative to that of feed sites as the supply of grain in triticale ears became depleted. In late winter artificial feed sites appear to provide an important source of food, as has been suggested for Corn Buntings (*Miliaria calandra*) by Brickle (1997).

Current set-aside regulations make provision for creating Wild Bird Cover within conventional arable systems. The pilot Arable Stewardship Scheme will also enable farmers to establish crops specifically for birds. These crops are likely to benefit breeding farmland seed-eaters such as Yellowhammers by increasing crop diversity and increasing the abundance of phytophagous invertebrate food. Wild Bird Cover planted with a mixture of seed-bearing crops could represent an important substitute for seeding weeds lost from the modern arable system as a result of intensification.

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# EFFECT OF CROPPING PRACTICE ON SKYLARK DISTRIBUTION AND ABUNDANCE

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## ABSTRACT

Skylark (*Alauda arvensis*) distribution was assessed by territory mapping during the breeding season on two intensive arable farms in Shropshire and Staffordshire. Sambrook Hall Farm in Shropshire had a cropping sequence comprising of winter wheat, sugar beet, potatoes, carrots and set-aside, whilst Manor Farm in Staffordshire consisted of winter wheat, winter oats, sugar beet, potatoes and set-aside. Four assessments were made between April and July 1996, marking all information on a visit map from which territory maps were compiled. As the season progressed, territory shifting took place with skylarks moving from winter cereals to set-aside, sugar beet and potatoes. This occurred when winter wheat had attained a height of 20cm and winter oats 25cm. The results show that there were significantly ($P<0.05$) more skylarks on non-rotational set-aside than winter cereals, potatoes and carrots. However, skylark numbers on sugar beet fields were not significantly different from those on other crops. Naturally regenerated set-aside situated along field margins was completely avoided throughout the season. Winter flocking counts were also carried out on four visits from October 1996 to February 1997. Skylarks on the two farms were either counted individually, or as groups varying in size from 5 to 20 birds. At Sambrook Hall Farm cereal stubble, which was left undisturbed prior to the establishment of sugar beet in spring, was the preferred winter feeding habitat for skylarks. On Manor Farm naturally regenerated or set-aside sown to grass provided the preferred winter feeding habitat in the absence of stubble.

## INTRODUCTION

The effect of agricultural practices on lowland bird populations is currently one of the major conservation concerns in the UK. Information based on the Common Birds Census and Atlas of Breeding Birds of the British Trust for Ornithology (BTO) indicates that many of the birds associated with farmland have shown population declines of 50-80% in the last 20 to 30 years (Campbell *et al.*, 1997). Similar trends are known to be occurring in other north-west European countries.

Whilst the contraction in range for the skylark was only 2% between 1969 and 1991, the Common Birds Census index on lowland farms decreased by approximately 58%. The decline in numbers has been attributed to a number of inter-related factors; the indirect effect of pesticides reducing the number of host plants and the invertebrates dependent on them (Stoate, 1996), changes in cropping patterns with a move from spring to autumn sown cereals

(Wilson *et al.*, 1995), loss of non-crop habitats (Lack, 1992) and increases in predator populations (Fuller *et al.*, 1995).

This study was designed to assess skylark distribution and abundance on two intensively managed arable farms in the West Midlands region of the UK over the breeding season and winter feeding period. The information collected would also show if the skylark had a preference for a particular crop type/habitat during these two periods.

## MATERIALS AND METHODS

Skylark distribution and abundance were assessed on two farms situated close to the Shropshire/Staffordshire border. Sambrook Hall Farm (91 ha), Sambrook, Shropshire (Grid reference SJ 718259) had a cropping rotation comprising winter wheat, sugar beet, potatoes, carrots and set-aside. The study area at Manor Farm (75 ha), Bishops Offley, Staffordshire (Grid reference SJ 778298) had a cropping sequence of winter wheat, winter oats, sugar beet, potatoes and set-aside.

Skylark distribution was assessed by territory mapping (Bibby *et al.*, 1992) during the breeding season. Four visits were made on 5 April, 25 April, 1 June and 21 June. Field maps and records were taken according to the fieldwork instructions of the British Trust for Ornithology survey of breeding skylarks (BTO, 1996). Each visit was completed in a single period, avoiding the first hour after dawn while completing the count by midday. Time, date and weather variables were recorded in order to eliminate bias during analysis. On the two farms fields were transversed at 50 metre intervals by walking along alternate tramlines, marking each bird with a standard symbol on a 1:25000 map. Symbols indicate both location of the bird and evidence of behavioural activities i.e. nesting, simultaneous movement, alarm etc. The skylark activity symbols used in this study were based on the BTO standard symbols with slight amendments to facilitate accurate analysis of visit maps and integration of species maps (Table 1).

Table 1. Skylark activity symbols used on territory maps

| Symbol | Behaviour/activity |
|---|---|
| $\bar{\underline{S}}$ | Rising from the ground in song. |
| $\underline{S}$ | Feeding on the ground in tramline. |
| S | Singing in the sky. |
| S x | Defending nest sight. |
| S S | The same skylark sighted twice. |
| S - - - - S | Skylarks sighted simultaneously. Indicates two birds from different territories. |
| S---x---S | Assumed pair. One skylark singing and adjacent bird rose in silence |

Four further visits were made during the autumn when flocking counts were recorded from October 1996 to February 1997. The skylarks were counted in groups of 5, 10 or 20 in October and November, but in the winter period reduced abundance allowed individual counting.

## RESULTS

Skylark territory maps for the four visits during the breeding season were combined in Figure 1 for Manor Farm, Bishops Offley. The rings drawn around the clusters do not necessarily define boundaries or indicate where birds may range over the summer (Bibby *et al.*, 1992). The cropping regime for this area is depicted in Figure 2, together with landscape features which influence the territories. The mean number of skylarks (expressed as numbers per ten hectares) recorded at each visit are presented in Table 2, together with the height of the crop or vegetation. As there was no significant difference between farms for the number of skylarks recorded for each crop, the results are presented as the mean of the Sambrook and Manor Farms.

The results show larger numbers of skylarks present in potatoes, sugar beet and winter wheat in May. Skylarks avoided set-aside adjacent to coniferous woodland and also carrots which

Table 2. Skylark numbers per 10 hectares for each crop type

| Crop | 2/5 | 25/5 | 1/6 | 21/6 | Mean |
|---|---|---|---|---|---|
| Sugar beet | 2.5 | 2.7 | 3.3 | 6.9 | 3.9 |
| Crop height(cm) | none | 2 | 4 | 15 | |
| Potatoes | 3.2 | 2.1 | 0.9 | 5.1 | 2.8 |
| Crop height(cm) | none | none | 2 | 25 | |
| Set-aside | 4.6 | 1.5 | 12.7 | 12.1 | 7.7 |
| Crop height(cm) | 5 | 7 | 10 | 18 | |
| Winter wheat | 2.9 | 3.1 | 1.1 | 0.3 | 1.9 |
| Crop height(cm) | 7 | 20 | 45 | 85 | |
| Winter Oats | 4.5 | 2.9 | 2.5 | 0 | 2.5 |
| Crop height(cm) | 4 | 15 | 25 | 60 | |
| Carrots | 0 | 0.8 | 0.8 | 3.9 | 1.4 |
| Crop height(cm) | plastic | plastic | plastic | 15 | |
| | | | | S.E.M. | 1.82 |

were covered with plastic sheet at this time. Skylark numbers increased in sugar beet in June, remained similar in potatoes, but declined in winter cereals. Similar trends were recorded for sugar beet, set-aside and winter wheat for Manor Farm, Bishops Offley. However, the striking difference on this farm was the increased numbers of skylarks on set-aside, which rose from 9.3/10 ha on 2 May to 18.5/10 ha on 21 June. There were significantly more skylarks on set-aside than winter wheat, winter oats, potatoes and carrots ($P<0.05$). These mean results represent crop preference over the whole season, but fail to highlight the progression in preference of skylarks for different crop habitats.

Figure 1. Skylark territory map for Manor Farm, Bishops Offley

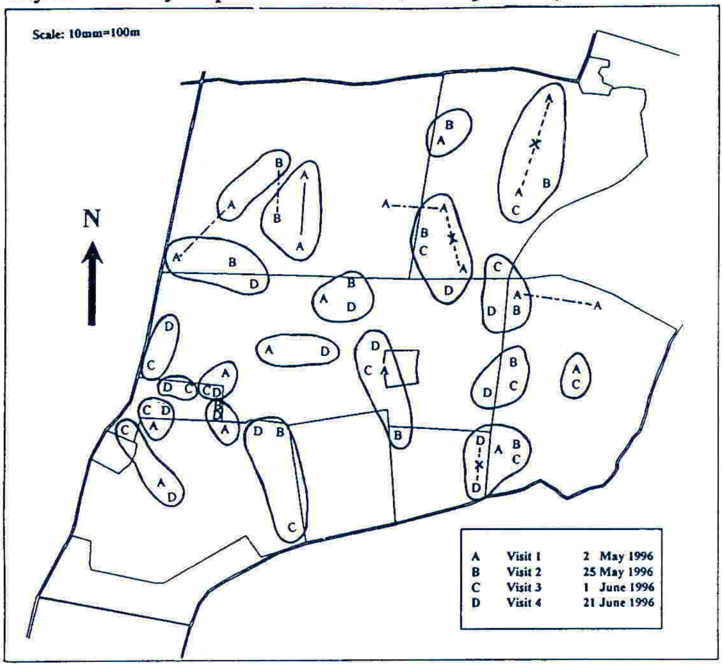
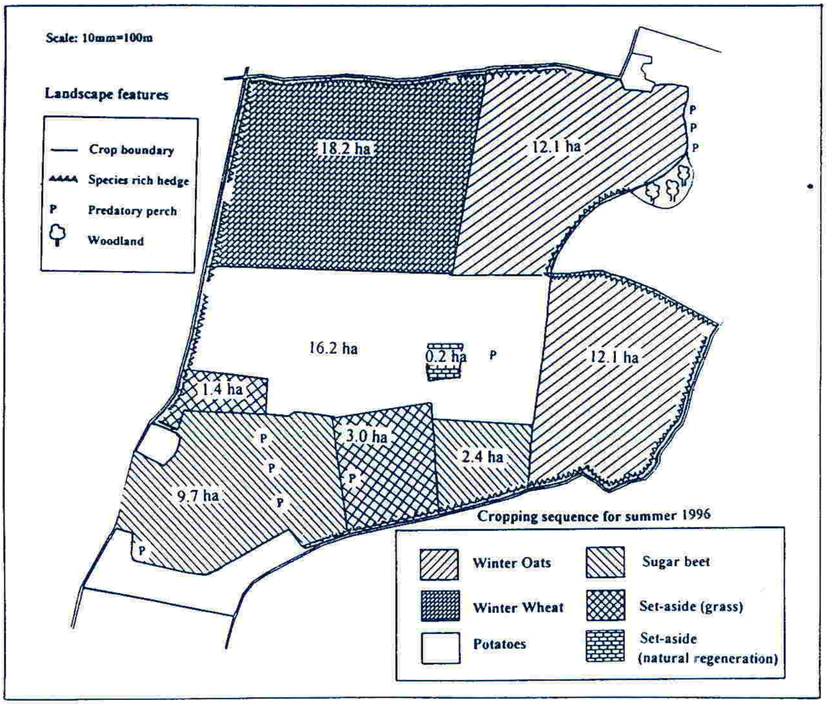



Figure 2. Cropping map with landscape features for Manor Farm, Bishops Offley



Winter flocking counts of skylarks (Table 3) show an overwhelming preference of birds for stubbles from October 1996 to December 1996, with some birds recorded in autumn sown cereals and following potatoes or sugar beet on Sambrook Hall Farm. At Manor Farm, where no stubbles remained in autumn, the highest numbers of skylarks were recorded on set-aside with some following sugar beet or potatoes and autumn sown cereals.

Table 3. Skylark abundance from autumn 1996 to winter 1997

| | Sambrook Hall Farm | | | | Manor Farm | | | |
|---|---|---|---|---|---|---|---|---|
| Crop type | Oct | Nov | Dec | Feb | Oct | Nov | Dec | Feb |
| Stubble | 130 | 30 | 30 | 15 | not present | | | |
| Set-aside (natural regeneration) | 0 | 0 | 0 | 4 | 0 | 30 | 10 | 4 |
| Set-aside (grass mix) | 0 | 0 | 0 | 0 | 4 | 4 | 10 | 4 |
| Fallow or roots | 0 | 0 | 0 | 5 | 1 | 4 | 5 | 5 |
| Autumn cereal | 3 | 0 | 0 | 7 | 0 | 0 | 5 | 5 |

## DISCUSSION

The skylark numbers recorded in Table 2 and the territory map (Figure 1) demonstrate territory shifting from autumn cereals at the beginning of June when potatoes, sugar beet, non-rotational set-aside and carrots became the preferred secondary habitats, with a limited number of breeding pairs maintaining their territories in winter wheat and winter oats. Many of the territories established in winter cereals incorporated more than one type of crop or were situated adjacent to non permanent boundaries between different crops. The territory shifting from winter wheat took place when the crop achieved a height of 20cm and was complete by 1 June when the crop was 45cm. In winter oats this transition took place at a slightly later date when the crop had reached 25cm. Other studies have reported similar territory shifting in response to increased crop height as the season progressed (Schapfer, 1988, Jenny, 1990).

Skylarks avoided non-rotational set-aside situated along field boundaries which was potentially a prime habitat for breeding birds in the spring and also a source of feed in the winter. This appears to have occurred because of the proximity of avian predator perch sites in standard trees located in the field or adjacent woodland as reported by Suhonen (1994). This modification of breeding and feeding behaviour in response to predation pressure would also account for skylarks failing to establish territories in food rich boundary habitats. This also underlines the importance of location in maximising the benefits of set-aside for farmland birds and indicates that whole field set-side could be more beneficial for skylarks than narrow strips around field boundaries.

The results of winter flocking counts indicate the preference of skylarks and other passerines for stubbles as the preferred feeding habitat in the autumn. Therefore in the main sugar beet growing areas of the UK (East and West Midlands, East Anglia, Fens, Lincolnshire and Yorkshire) there is the potential to encourage, advise or provide incentives for farmers to maintain stubbles in the autumn and refrain from applying herbicides until the spring.

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# THE MANAGEMENT OF SET-ASIDE WITHIN A FARM AND ITS IMPACT ON BIRDS

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## ABSTRACT

At ADAS Boxworth in Cambridgeshire on a clay soil, a range of seed mixtures were established on set-aside land from autumn 1993 to autumn 1994. Four grass-based seed mixtures were sown. These included a basic mixture aimed at minimising cost and weed problems, a tussocky mixture to provide extra environmental benefit with minimum increase in cost, a diverse mixture of more native grasses and the diverse grass mixture with wildflowers. Additionally, a 'bee mixture' was sown to provide nectar for bees and other insects. Monitoring of the vegetation, invertebrates, small mammals and birds was undertaken. Results show that distinct grassland habitats could be created at relatively low cost. Indications were that use of the set-aside strips by birds was greater than of the adjacent crop. More than half the species, but only about 20% of individuals recorded were observed using the set-aside strips in both years. Use of set-aside was greatest on the more diverse mixes. The spatial scale of field boundary set-aside and the quality of the adjacent habitat are the key factors in determining bird use.

## INTRODUCTION

The first European Community (EC) Set-aside Scheme came into operation in July 1988. The 5-year scheme was voluntary and designed to reduce surpluses of arable crops. Compensation payments were available for taking a proportion of arable land out of production and managing it within defined conditions. In August 1991 the EC one-year Set-aside Scheme was introduced, which was also voluntary. In May 1992 it was announced that set-aside would be part of the reform of the EC Common Agricultural Policy. Farmers were required to set-aside 15% of their total area of cereals, oilseeds and protein crops as rotational set-aside, or from 1993 a higher 18% (in UK) as non-rotational set-aside (NB rates were lower in some years).

The rules of set-aside require certain management conditions to be followed, but these allow sufficient flexibility to achieve varied objectives (Anon, 1994). The farm-scale set-aside project at ADAS Boxworth and ADAS Bridgets aims to demonstrate the use of set-aside on a farm scale whilst maintaining and enhancing the wildlife, habitat, landscape and historic value of the farm within a practical, efficient and cost-effective farming system.

At the start of the project Integrated Land Management Plans (Hares *et al.*, 1996) were initiated for both sites to identify those areas where set-aside margins or field blocks should be established. These plans take into consideration the impact of set-aside on the local landscape, the preservation or enhancement of current archaeological or environmental features, the potential for improvement in value of set-aside areas and their benefit to wildlife and the economic implications of setting aside land within specified rotations and defined soil types under current legislation. Details of how the location of the set-aside was chosen to maximise the objectives (Hares *et al.*, 1996) and the choice and management of plant covers, together with details of their establishment (Clarke *et al.*, 1996) have already been published elsewhere. This paper considers the results of the bird monitoring at ADAS Boxworth where detailed annual recording has been undertaken.

## MATERIALS AND METHODS

ADAS Boxworth in Cambridgeshire is a 347 ha farm on a chalky boulder clay soil. On the approximately 290 ha of arable land the main crops grown are winter wheat, winter oilseed rape and winter beans. In 1997, the area of set-aside was about 10% of the area of cereals, oilseeds, linseed and pulses. The majority was managed as non-rotational, predominantly field margin (at least 20 m wide) set-aside, and there is a small proportion of rotational set-aside in years when a greater overall proportion of set-aside is required. All the areas sown to each mixture were at least 20 m wide and over 100 m long.

A range of seed mixtures was established using a conventional farm drill from autumn 1993 to autumn 1994. Species composition of the seed mixture was chosen to reflect the soil and climatic conditions (Table 1). The basic grass mixture was selected to be cheap and provide rapid ground cover to minimise the invasion from arable and undesirable weeds (Clarke, 1995). A tussocky mixture was chosen to provide potentially greater benefit for ground nesting birds, small mammals and invertebrates, whilst still maintaining the objective of minimising weed problems and being cost-effective. Rye-grass was included to provide cover in the early years and, as expected, it declined as a proportion of the cover by the third year. The diverse grass mixture contained seed of species more typical of semi-natural grasslands in the area, some of which are considered to be less vigorous and is readily available from seed merchants. A wildflower mixture was included in order to evaluate the benefits of these more expensive mixtures, in particular for insects, small mammals and birds. In addition, a small area of a mixture (Tübingen Mischung) from Germany designed to provide nectar for bees and other insects has been established (Engels *et al.*, 1994). Selected set-aside areas were monitored in relation to botanical composition, invertebrate and small mammal populations, butterfly abundance and use by breeding and overwintering birds.

A total of fifteen 100 m strips of set-aside were selected for field observations. These strips included examples of each of the five main set-aside types (Basic grass mix; Tussocky grass mix; Diverse grass mix; Wildflower/grass mix; Bee mixture). These were selected in order to provide a representative sample of the set-aside on the farm, but were not replicated adjacent to the same crop and boundary features. An ornithologist visited each of the strips on 10 occasions between June and September in 1995 and July - October in 1996. Each visit was carried out either in the early morning or late afternoon / early evening, in order to coincide with peak bird activity. Surveys were only carried out in suitable weather conditions, and no surveys were carried out when conditions were excessively hot, windy or during rain (Bibby *et al.*, 1992).

Table 1. Composition of seed mixtures, seed rates (kg/ha) and costs of seed (£/ha)

| Scientific name | Common name | Seed rate (kg/ha) |
|---|---|---|
| **Basic grass mixture** | Approx. seed cost | £15/ha |
| *Cynosurus cristatus* | Crested dog's tail | 5.00 |
| *Lolium perenne* | Late perennial rye-grass | 5.00 |
| *Poa pratensis* | Smooth meadow-grass | 5.00 |
| | Total seed rate | 15.00 |
| **Tussocky grass mixture** | Approx. seed cost | £17/ha |
| *Dactylis glomerata* | Cock's-foot | 3.75 |
| *Festuca rubra* var. *rubra* | Red fescue | 2.25 |
| *Lolium perenne* | Late perennial rye-grass | 7.50 |
| *Phleum pratense* | Timothy | 1.50 |
| | Total seed rate | 15.00 |
| **Diverse grass mixture** | Approx. seed cost | £70/ha |
| *Agrostis capillaris* | Common bent | 0.75 |
| *Cynosurus cristatus* | Crested dog's tail | 3.00 |
| *Festuca ovina* | Sheep's fescue | 3.00 |
| *Festuca rubra* ssp. *commutata* | Red (chewings) fescue | 2.25 |
| *Festuca rubra* ssp. *pruinosa* | Slender red fescue | 3.75 |
| *Poa pratensis* | Smooth meadow-grass | 2.25 |
| | Total seed rate | 15.00 |
| **Grass + wildflower mixture** | Approx. seed cost | £300/ha |
| | Diverse grass mixture | 15.00 |
| *Achillea millefolium* | Yarrow | 0.24 |
| *Centaurea nigra* | Black knapweed | 0.42 |
| *Galium verum* | Lady's bedstraw | 0.42 |
| *Leucanthemum vulgare* | Ox-eye daisy | 0.30 |
| *Lotus corniculatus* | Bird's-foot-trefoil | 0.42 |
| *Primula veris* | Cowslip | 0.30 |
| *Prunella vulgaris* | Selfheal | 0.45 |
| *Ranunculus acris* | Meadow buttercup | 0.45 |
| | Total seed rate | 18.00 |
| **Bee mixture** | Approx. seed cost | £35/ha |
| *Phacelia tanecetefolia* | Phacelia | 2.80 |
| *Fagopyrum esculentum* | Buckwheat | 1.75 |
| *Sinapsis alba* | White mustard | 0.49 |
| *Coriandrum sativum* | Coriander | 0.42 |
| *Calendula officinalis* | Field marigold | 0.35 |
| *Nigella sativa* | Black cumin | 0.35 |
| *Raphanus sativus* | Red radish | 0.21 |
| *Centaurea cyanus* | Cornflower | 0.21 |
| *Malva sylvestris* | Common mallow | 0.21 |
| *Anethum graveolens* | Dill | 0.14 |
| *Borago officinalis* | Borage | 0.07 |
| | Total seed rate | 7.00 |

Each survey consisted of a timed, 15 minute fixed point observation. During this period, all birds were recorded and identified to species and their activity (e.g. feeding) noted. The location of each individual was recorded within one of three categories: in the field boundary, in the set-aside strip or in the crop. Any movement of individual birds between these areas and the duration of stay was recorded. Where the same individual was seen on more than one occasion, this was also noted. At the end of each count, the strip was walked in order to flush any birds which may have been present but not visible from the observation point (e.g. this was often the case for gamebirds foraging in the strips). Birds overflying the strips were only recorded when they were actively foraging over the strips, adjacent field boundary or crop (e.g. kestrels (*Falco tinnunculus*) hovering over the strip). The repeated visits through the season were used to calculate mean number of birds recorded per set-aside strip.

## RESULTS

The number of birds recorded in the surveys, using all habitats across all sections and visits was greater in 1995 (1344) than in 1996 (505). In 1995 some 44 species were recorded, with 31 species in 1996. Some 69% of all birds counted (67% in 1995), comprising 25 species, were observed using the field boundaries, especially hedgerows. In 1995, 63% of the 44 species recorded, were at some time observed in the set-aside strips. The figure in 1996 was about 50%. In 1996, 15 species were observed using the strips, representing 19% of the total individual birds counted in the study (21% in 1995). The number of individuals using the crop (i.e. beyond the strip) was 69 (5.1% of the total) in 1995 and 48 (9.5% of the total) in 1996, comprising 15 and 10 species respectively. The number of birds recorded moving from the boundary to the strip, boundary to the crop, or strip to the crop, represented 18% of the total in 1995, but only 3% in 1996. It appeared that the type and management of the field boundary strongly influenced the number of birds using each section.

The species using the set-aside strips in 1996 were, in order of abundance, yellowhammer (*Emberiza citrinella*), red-legged partridge (*Alectoris rufa*), pheasant (*Phasianus colchicus*), skylark (*Alauda arvensis*), wood pigeon (*Columba palumbus*), greenfinch (*Carduelis chloris*), linnet (*Carduelis cannabina*), carrion crow (*Corvus corone*), reed bunting (*Emberiza schoeniclus*), kestrel, meadow pipit (*Anthus pratensis*), yellow wagtail (*Motacilla flava*), dunnock (*Prunella modularis*), blue tit (*Parus caeruleus*), and goldfinch (*Carduelis carduelis*). The three species most commonly recorded using the set-aside strips were the same in both years i.e., yellowhammer, red-legged partridge and pheasant, which in 1995 accounted for 54% of the total bird community abundance, and 36% in 1996. No gamebirds were reared on the farm and all birds were therefore considered to be wild. Although these more common species are mainly gramnivorous species they all eat invertebrates during the summer period. The fact that more individuals and species were observed using the strips rather than the crop, is important and supports the claim that strips do provide added wildlife value. Whole field set-aside, however, would probably offer better overall feeding and breeding conditions for the range of birds observed, though densities would still be low. One of the difficulties posed by surveying birds on farmland is their relatively low density and bias towards using field boundaries and the edges of crops rather than the centres.

The 'bee' mixture (although only one strip was monitored) had the highest bird usage in both years (Table 2), with most of the yellowhammers being recorded here. Above average

Table 2. Mean number of individual birds and total number of species recorded using different types of set-aside strips

| | | 1995 | | 1996 | |
|---|---|---|---|---|---|
| | No. strips | Mean no. individuals | No. of species | Mean no. individuals | No. of species |
| Basic grass mixture | 3 | 71 | 30 | 18 | 16 |
| Tussocky grass mixture | 4 | 121 | 24 | 41 | 19 |
| Diverse grass mixture | 4 | 81 | 33 | 42 | 23 |
| Grass + wildflower mixture | 3 | 100 | 25 | 33 | 16 |
| 'Bee' mixture | 1 | 131 | 15 | 45 | 8 |

numbers of birds were recorded using the tussocky grass and grass + wildflower mixes in 1995 and the tussocky and diverse grass in 1996. Lowest bird usage was recorded in the basic grass in both years, although a large number of species was recorded in this set-aside strip type in 1995. Since the treatments in this study were not all replicated adjacent to similar boundary features and crops, this was considered to be an observational study. However, these results are considered indicative of bird usage of set-aside strips, although more thoroughly replicated field trials would be required to confirm this.

## DISCUSSION

In both years, the best set-aside strips seemed to be next to tall, structurally diverse hedges, which have been managed for conservation benefits at Boxworth over recent years. Those in open fields or adjacent to fences were little used. Consequently, the adjacent habitat type and the structural features of the set-aside strips, may have over-riding importance to their potential use by birds. Many of the strips with a tussocky or more open structure, offer less dense habitat to birds which may be of benefit in enabling them to feed more easily, to gain access to food more readily, and to avoid getting wet since dense vegetation holds more moisture.

Field boundary set-aside has some value for birds and is used principally by granivorous-feeding species. These are the species most affected by the intensification of agriculture and changes to farm practices in the past 25 years, especially the dominance of autumn-sown cereals which has removed winter stubble habitats (Campbell *et al.*, 1997). These strips offer additional habitat within the farmland mosaic and could provide important feeding areas during the breeding period for a range of farmland birds. Location is important in terms of the value of its contribution to farmland wildlife. Margins next to tall, structurally diverse hedges, provide the best combination of habitats, since many passerine birds favour the availability of cover to avoid predation. As a nesting habitat, field-boundary set-aside provides sites for species such as red-legged partridge, pheasant, grey partridge (*Perdix perdix*) and reed bunting, but has less to offer for some species. Personal observations suggest that skylarks have been using the 20m wide strips at Boxworth. This may reflect that a combination of size and management, allowing the birds open views, can benefit species normally considered as requiring field centres. The best mixture should be a diverse tussocky grass mix or the 'bee' mixture. A diverse structure is important as, probably, are some open bare ground patches from which spilt seeds are more easily collected by birds than from rank grass. More open vegetation also probably enables birds to gain access to, and catch, invertebrates. Red-legged partridges, and even the passerine species, tend to walk through the cover, taking food along the way and picking insects off the vegetation. Cutting in late summer may improve its value to wildlife as a feeding habitat (after the nesting season) by opening it up. Many of these bird species prefer open rather than closed canopy habitats, so cutting opens up the structure. Tall rank grass should be avoided as the planting regime since it is little used by birds. Finally, this study was only able to assess small blocks of habitat. The true value of field-margin set-aside would be where it provides a mosaic of habitat within the infrastructure of the landscape. Larger amounts of it would undoubtedly prove valuable to birds and other wildlife. Wide strips within open fields would also be useful for nesting skylarks and potentially corn buntings. The spatial scale of field-boundary set-aside, together with the quality of the adjacent habitat (the field-boundary itself) are the over-riding factors determining bird use and hence conservation value on the farm. The size of blocks or strips and their management requires further experimental investigation in order to maximise the benefits of uncropped habitat created on the farm.

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# THE USE OF GAME COVER AND GAME FEEDERS BY SONGBIRDS IN WINTER

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## ABSTRACT

A study of the use of game cover and game feeders by songbirds in winter was conducted on a large open arable and mixed farming area of the South Downs in West Sussex. Results showed that corn bunting (*Miliaria calandra*), reed bunting (*Emberiza schoeniclus*), yellowhammer (*Emberiza citrinella*) and linnet (*Carduelis cannabina*) all made considerable use of game feeders situated in kale strips or in scrub. The use of game feeders by songbirds has been little documented, this study has shown they can be of considerable value.

## INTRODUCTION

Many farmland songbirds are in drastic decline in Britain, including corn bunting (*Miliaria calandra*), reed bunting (*Emberiza schoeniclus* ), yellowhammer (*Emberiza citrinella*), linnet (*Carduelis cannabina*) and skylark (*Alauda arvensis*) (Marchant *et al* 1990). Possible reasons for this decline relate to changing farming practices and the changing face of arable land in Britain (O'Connor & Shrubb, 1986). Major factors may include lower breeding success due to reduced invertebrate food availability (Potts, 1991, Campbell *et al,* 1997) and increased mortality in winter through loss of traditional food sources.

### Changes in winter food availability

The availability of traditional winter feeding sites has been reduced with the loss or reduction of stubble fields, stack yards, cattle pens and accessible grain stores. Stubbles as an early winter source of weed seed and spilt grain have decreased with the large-scale change to autumn sown cereals, and their quality to birds has declined with the increased use of herbicides and improved harvesting techniques. Cattle feed as a food supply has decreased with changes in stock management, notably indoor housing of cattle in winter. Improved farm storage facilities, often motivated by health and safety regulations, mean that birds rarely have access to grain stores in winter. Increased specialisation of farms and regions has led to fewer mixed farms with the result that cattle feed has disappeared from cereal growing areas. Moreover a reduction in the practise of undersowing, a frequent component of mixed farming, also removes a reason for stubbles being left over winter.

### Game feeders and game cover

The provision of game feeders is a common practice on farms with a game shooting interest. Grain or specialised food pellets are provided in hoppers for pheasant (*Phasianus* *colchicus*), grey partridge (*Perdix perdix*) and red-legged partridge (*Alectoris rufa*). Grain is frequently spilt around these hoppers and may also be spread loose, so becoming available to songbirds. Game cover strips are largely used as holding cover for gamebirds, particularly in open areas, where crops of brassicas notably kale are often planted. Recently work has been published on their use in providing a winter food source as well as cover, both for game and songbirds. The sowing of food plants such as millet, maize, oilseed rape, quinoa and others has been advocated (Straker 1997). Under present set-aside management regulations (Wild Bird Cover option), set-aside land can be planted with suitable cover mixtures. Deliberately leaving strips of un-harvested cereals has the same effect of providing cover and food.

The observations in this paper were made during the course of an intensive autecological study of the corn bunting started in 1995. This paper assesses the use of game feeders and game strips found on the study site by five declining farmland songbirds, corn bunting, reed bunting, yellowhammer, linnet and skylark in relation to other habitats present in the winter.

## STUDY SITE AND METHODS

The study site on the South Downs in West Sussex, north of Worthing included three farms covering approximately 10 $km^2$ .The landscape was very open, dominated by large cereal fields and both rotational and non-rotational grass. Few hedgerows and scrub/wood patches were present, totalling less than 3% of the area.

Game feeders were provided in two habitats: kale strips left as game cover, and in small patches of scrub/wood or hedgerow. Kale strips were typically about 10-20 m wide and between 50 m and 200 m long and all contained first-year kale. Scrub/wood patches were all under one hectare. Game feeders were kept provisioned with wheat or barley seed from October 1996 to March 1997. Strips of stubble were deliberately left in some areas as game cover. Other stubble included those fields destined to be spring cereals (all ploughed before late December), undersown cereal fields destined to be grass leys, and rotational set-aside. The average area of each habitat type in the winter of 1996/97 is shown in Table 1.

Table 1. Average percentage availability of habitat types on the Sussex study area in winter 1996/97

| Habitat type | Mean percentage of study area |
|---|---|
| Stubble | 15.2 |
| Cattle feed | 6.8 |
| Kale Game Cover strips with feeders | 0.3 |
| Brassicas (without feeders, usually as fodder) | 2.1 |
| Scrub/wood with feeders | 0.5 |
| Scrub/wood | 2.3 |
| Other arable crops and grassland | 72.8 |

Birds were surveyed by walking to within 50 m of every point of every field. All species were recorded. The number of flocks and the number of individual birds in each flock were noted. The position of flushed birds/flocks were noted to reduce as far as possible the chance of double counting. Seven surveys were conducted between 5th November 1996 and 18th February 1997, approximately fortnightly, in any weather except heavy rain.

## STATISTICAL ANALYSIS

Compositional analysis (Aebischer, *et al* 1993) was used to compare habitat use (proportion of birds in a habitat type) to habitat availability (proportion of the study site which belongs to that habitat type) in order to respect the constrained data structure. Two analyses were conducted, one for individual birds and one for flocks (one or more birds) in order to take account of the non-independence of flocking birds.

The habitat use of each species was first tested for overall departure from random by using Wilk's $\Lambda$. Then the differences in relative use between habitats were determined, both for individuals and for flocks. The two sets yielded very similar results. Only the results for the analysis of individuals are reported here.

## RESULTS

The total number of each species recorded are shown in Table 2.

Table 2: Total number of individuals and flocks recorded in during winter 1996/97

| Species | Total Individuals | Total Flocks (1+ birds). |
|---|---|---|
| Corn Bunting | 1250 | 69 |
| Yellowhammer | 122 | 19 |
| Reed Bunting | 78 | 15 |
| Linnet | 493 | 16 |
| Skylark | 3001 | 153 |

The overall habitat use of each species showed significant departure from random, but not at a high level of significance, possibly due to the small sample size and high number of habitat types used. The differences in relative use of habitats compared to availability for each species are summarised below and shown in full in Appendix 1, the values of Wilk's $\Lambda$ are also shown in Appendix 1.

Corn Bunting: Game feeders in scrub/woods, cattle feed and stubble were the most used habitat types, all were used significantly more than other arable crops and grassland. Game feeders in scrub/woods were used significantly more than scrub/woods without feeders.

Yellowhammer: Game feeders in scrub/woods were the most used habitat type, followed by kale strips with feeders. Both habitat types were used significantly more than the respective habitats types without feeders, and more than other arable crops and grassland.

Reed Bunting: Kale strips with feeders were the most used habitat type and were used significantly more than brassicas without feeders. Scrub/woods, with or without feeders, and cattle feed were used significantly more than other arable crops and grassland.

Linnet: Stubble and kale strips with feeders were the most used habitat types. All habitat types were used significantly more than other arable crops and grassland.

Skylark: Stubble was used significantly more than all other habitat types.

Only Skylarks did not make use of either game cover strips with feeders or game feeders in scrub/woods. In three out of five cases birds made significantly greater use of the game cover strips with feeders or game feeders in scrub/woods than the contrasting groups of brassicas and scrub/wood without feeders respectively. In the other two cases the habitat types with feeders ranked higher than those without.

## DISCUSSION

Where present, game cover and feeders can be an important winter habitat for farmland songbirds and their value as such should not be overlooked. The greater use of the habitat types with feeders compared to the similar ones without feeders strongly suggests that it is the continuous availability of food that provides the main attraction. Nevertheless on a study site such as this where hedges are virtually non-existent and there are only small patches of wood/scrub the value of game cover strips was probably enhanced.

Stubbles were an important habitat type but its area was greatly reduced by the end of December as fields were ploughed prior to sowing spring cereals. Stubbles remained only as rotational setaside, deliberately left strips for game and undersown leys. Cattle feed became an important food supply for corn buntings in mid winter but appears not to attract linnets, yellowhammers or reed buntings. These species possibly prefer to feed nearer cover. Brassicas as fodder crops also have some attraction to farmland songbirds.

Despite low sample sizes, this study has shown that game cover and feeders can be important to farmland songbirds in winter. A study aimed directly at investigating their use would provide interesting results.

## CONCLUSIONS

Game cover strips and game feeders can provide an important winter habitat for farmland songbirds. The continuous provision of food at such sites may have an important survival benefit to these birds particularly during periods of extreme cold or snow cover when other sources of food are less available.

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## APPENDIX 1.

Ranking matrices based on proportional habitat use during surveys compared to habitat availability at the time of the survey. Wilk's $\Lambda$ shows the overall departure from random; individual matrices show relative habitat use. A positive sign represents a greater relative use of the row factor over the column factor, a negative sign a lesser relative use. If the sign is tripled the greater or lesser use is significant at $p<0.05$.

1. Yellowhammer (Wilk's $\Lambda$=.0006, F=275.43, df=6,1,sig.=0.046)

| | Stubble | Cattle | Fd:scrub | Fd:Kale | Brassica | Scrub | Other | RANK |
|---|---|---|---|---|---|---|---|---|
| Stubble | | + | - | - | + | - | +++ | 4 |
| Cattle | - | | --- | --- | --- | --- | +++ | 6 |
| Feed:scrub | + | +++ | | + | +++ | +++ | +++ | 1 |
| Feed:Kale | + | +++ | - | | +++ | + | +++ | 2 |
| Brassica | - | +++ | --- | --- | | - | +++ | 5 |
| Scrub | + | +++ | --- | - | + | | +++ | 3 |
| Other | --- | --- | --- | --- | --- | --- | | 7 |

2. Reed Bunting (Wilk's $\Lambda$=.00046, F=358.75, df=6,1, sig.=0.04)

| | Stubble | Cattle | Fd:scrub | Fd:Kale | Brassica | Scrub | Other | RANK |
|---|---|---|---|---|---|---|---|---|
| Stubble | | + | - | - | - | - | + | 5 |
| Cattle | - | | --- | --- | --- | - | +++ | 6 |
| Feed:scrub | + | +++ | | --- | - | - | +++ | 4 |
| Feed:Kale | + | +++ | +++ | | +++ | +++ | +++ | 1 |
| Brassica | + | +++ | + | --- | | + | +++ | 2 |
| Scrub | + | + | + | --- | - | | +++ | 3 |
| Other | - | --- | --- | --- | --- | --- | | 7 |

3. Corn Bunting (Wilk's $\Lambda$=.00007, F=2293, df=6,1, sig.=0.016)

| | Stubble | Cattle | Fd:scrub | Fd:Kale | Brassica | Scrub | Other | RANK |
|---|---|---|---|---|---|---|---|---|
| Stubble | | + | - | + | +++ | +++ | +++ | 2 |
| Cattle | - | | --- | + | +++ | +++ | +++ | 3 |
| Feed:scrub | + | +++ | | +++ | +++ | +++ | +++ | 1 |
| Feed:Kale | - | - | --- | | + | +++ | + | 4 |
| Brassica | --- | --- | --- | - | | + | + | 5 |
| Scrub | --- | --- | --- | --- | - | | + | 6 |
| Other | --- | --- | --- | - | - | - | | 7 |

4. Linnet (Wilk's $\Lambda$=.00041, F=403.28, df=6,1, sig.=0.038)

| | Stubble | Cattle | Fd:scrub | Fd:Kale | Brassica | Scrub | Other | RANK |
|---|---|---|---|---|---|---|---|---|
| Stubble | | +++ | +++ | + | + | +++ | +++ | 1 |
| Cattle | --- | | - | - | - | - | +++ | 6 |
| Feed:scrub | --- | + | | - | - | + | +++ | 4 |
| Feed:Kale | - | + | + | | + | +++ | +++ | 2 |
| Brassica | - | + | + | - | | + | +++ | 3 |
| Scrub | --- | + | - | --- | - | | +++ | 5 |
| Other | --- | --- | --- | --- | --- | --- | | 7 |

5. Skylark (Wilk's $\Lambda$=.00062, F=268.21, df=6,1, sig.=.047)

| | Stubble | Cattle | Fd:scrub | Fd:Kale | Brassica | Scrub | Other | RANK |
|---|---|---|---|---|---|---|---|---|
| Stubble | | +++ | +++ | +++ | +++ | +++ | +++ | 1 |
| Cattle | --- | | + | - | - | + | + | 4 |
| Feed:scrub | --- | - | | - | - | + | + | 5 |
| Feed:Kale | --- | + | + | | - | +++ | + | 3 |
| Brassica | --- | + | + | + | | + | + | 2 |
| Scrub | --- | - | - | --- | - | | - | 7 |
| Other | --- | - | - | - | - | + | | 6 |

# TIMING THE CULTIVATION OF ROTATIONAL SET-ASIDE FOR GRASS WEED CONTROL TO BENEFIT CHICK-FOOD INSECTS

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## ABSTRACT

Graminivorous sawflies are important beneficial farmland insects, occurring at densities too low to cause crop damage but providing an essential source of food for the chicks of many birds of arable habitats. These sawflies overwinter as pupae in the soil and emerge as adults in the spring. Cultivation of the soil during the overwintering period is believed to disturb the insects and cause high mortality; cereal fields that are not ploughed after harvesting such as undersown spring barley fields have been found to provide key overwintering sites. Rotational set-aside following cereals would similarly provide a refuge for overwintering sawflies provided that any cultivation of the soil for weed control takes place after adult emergence is complete. The phenology of sawfly emergence has been investigated and peak emergence found to be in early May. Experiments conducted at the same time showed that two of the main grass weeds of set-aside land, black-grass (*Alopecurus myosuroides*) and barren brome (*Bromus sterilis*) did not set their first viable seeds until late May or early June. Management of set-aside land by cultivation after the third week of May will therefore successfully permit emergence of overwintering sawflies without prejudicing grass weed control.

## INTRODUCTION

The last 40 years has seen an alarming decline in the abundance of many of the birds associated with farmland habitats (Tucker & Heath, 1994), and this is being increasingly linked with food shortages for birds in such habitats (Campbell *et al.*, 1996). A shortage of insect food, although partly related to pesticide use, has also been linked to changes in cultural practices. Larvae of the sawfly (Hymenoptera: Symphyta) species that occur in cereal fields are one insect group identified as a preferred item in the chick diet of the grey partridge (*Perdix perdix*) (Potts, 1986), which is one of the most severely declining UK bird species. They are also known to be important in the diet of other farmland birds, such as pheasants (*Phasianus colchicus*) (Hill, 1985), corn buntings (*Miliaria calandra*) (Aebischer & Ward, 1997) and skylarks (*Alauda arvensis*) (Poulsen, 1993). The most common sawflies in cereal habitats are species of the genus *Dolerus*, which are univoltine with a brief adult flight period in spring and a larval stage lasting from May to July. These species then overwinter as pupae in the soil, and are susceptible during this phase to mortality from disturbance through soil cultivation. The process of undersowing spring cereals with ley grass in mixed arable farming systems traditionally supplied areas where sawflies were not subject to overwintering disturbance so that they provided sources of emerging adults that could recolonise surrounding areas (Potts & Vickerman, 1973), but this practice is now uncommon. One-year naturally-regenerated set-aside following cereals could potentially replace this habitat in providing a refuge from overwintering mortality and therefore help to maintain sawfly populations on farmland, provided it remains uncultivated until adult spring emergence has occurred.

However, set-aside management needs to ensure effective weed control; one major disadvantage of allowing natural regeneration to occur on set-aside land is the potential opportunity it provides for the establishment of annual grass weeds. Without proper control, a year's fallow between arable crops allows high seed return from annual grasses, greatly increasing the size of the seed bank (Clarke & Froud-Williams, 1989) and ensuring the continuity of problems with weeds such as *A. myosuroides* and *B. sterilis*. To be effective, weed control must be timed correctly as there is evidence that seeds become viable some time before they are shed. Seed heads on *A. myosuroides* and *B. sterilis* can appear in early May on overwintering plants (Wilson, 1988). Early and frequent cutting has been suggested as an effective control mechanism, although there are still potential problems as repeat flowering occurs at progressively lower heights (Shield & Godwin, 1992). On set-aside land in Britain, control measures can be carried out only within the regulations of the Arable Area Payments Scheme. In 1992/93, this allowed cutting the vegetation or cultivation of the soil for summer fallow from 1 May. The early cultivation option has been much less used since the option to spray with non-selective herbicide was introduced as a third alternative in 1994. Cultivation can now not be carried out before 1 July unless a green cover is replaced by sowing, but where used it has the potential to interfere with the successful emergence of sawflies from land which otherwise could provide an ideal undisturbed habitat over the winter.

## METHODS

### Phenology of sawfly emergence

Adult sawflies were caught at emergence using 1 m x 1 m square wooden traps with a 1.5 mm mesh diameter netting lid. A water trap was used as a collector in each emergence box; these traps were 225 mm x 130 mm metal trays, 40 mm deep, sprayed yellow and filled with a dilute solution of detergent. This design is known to be effective at catching sawflies (Barker *et al.*, in press). Emergence traps were sealed at the base with a 5 cm soil bank on each side. Trapping was carried out on a farm at Damerham, in Hampshire, during the spring from 1993-1995. In 1993 and 1994 twelve traps were put out in each of two fields, spaced at 10 m intervals in a single line; in 1995, 144 traps were laid out in one of these fields in a 12 by 12 grid, with 0.6 m between traps. The fields were cropped as herbage seed (perennial rye-grass *Lolium perenne* L.) in 1993 and winter wheat in 1994 and 1995. Traps were checked twice weekly and all sawflies collected from the water traps; these were not 100% efficient so care was taken also to collect any live adult sawflies present in the boxes. Trapping was started in late April in 1993 and early April in 1994/1995. All sawflies were identified to species and cumulative emergence curves were plotted for *Dolerus* spp. adults.

Weed seed viability

The development of viability in *A. myosuroides* and *B. sterilis* seeds was investigated using seeds from two set-aside sites in Hampshire and one in Leicestershire in 1993. Plants of these two grass species were marked on the sites when the first ears emerged: 11 May in Hampshire and 17 May in Leicestershire. At weekly intervals from these dates until the end of June, 25 seed heads of *A. myosuroides* and 25 ears of *B. sterilis* were collected at random from the marked patches. All the seeds from the sampled heads were separated and three replicates of 100 randomly selected *A. myosuroides* seeds or 40 *B. sterilis* spikelets were placed on moist glass filter paper in Petri-dishes. *A. myosuroides* seeds were kept in an incubator at 16 h light: 8 h dark, 20°C light and 14°C dark temperatures. *B. sterilis* seeds were kept at ambient temperatures in the dark, since light is known to enforce dormancy. The dishes were kept moist with distilled water and examined every two days; germinated seeds were counted and removed. Each dish was maintained until there was no further change for at least a four-day period.

## RESULTS

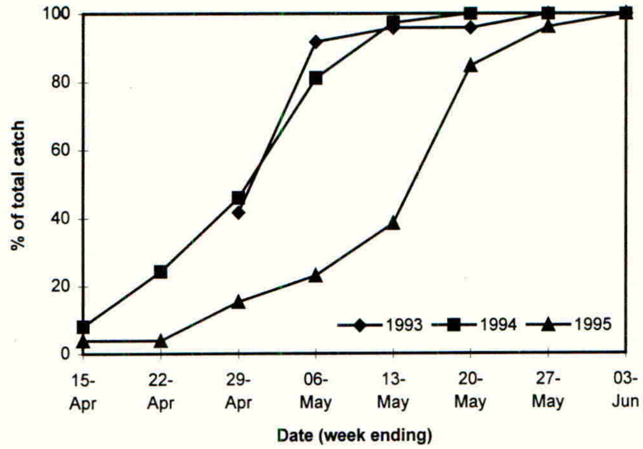
Sawfly emergence

The majority (over 90%) of the adult sawflies emerging on the trapped areas in all three years were adults of the genus *Dolerus*. In 1993, a total of 24 *Dolerus* spp. adults emerged from an area of $24m^{-2}$. In 1994, when the trapping period was extended into early April, this rose to 37 adults in $24m^{-2}$; densities of emerging adults were lower in 1995 with only 26 adults in $144m^{-2}$. In all three years peak emergence was in May (Figure 1), although it was later in 1995 - the third rather than the first week. Emergence finished soon after this peak, so that about 90% of adults had emerged by the end of the third week in May in 1993 and 1994 and 85% by the end of the third week in 1995.

Weed seed viability

The percentage of seed germinating from each sampling date for *A. myosuroides* and *B. sterilis* is shown in Figures 2.1 and 2.2. The first *A. myosuroides* seed from Hampshire germinated from the seeds collected on 18 May, but most seeds on this date were green and empty. Germination of this species peaked in early June for all populations without ever reaching 100% and then declined, presumably at the onset of summer dormancy. *B. sterilis* seed became viable from 24 May at the Hampshire sites, rising rapidly to full viability in early June; germination started slightly later in Leicestershire but seeds here were fully viable by from the second week of June. Overall, seeds of both weed species on set-aside land were increasingly becoming viable from the last week of May and reached peak germination ability in early June.

Figure 1. Cumulative catch of adult *Dolerus* spp. sawflies in emergence traps in spring 1993, 1994 and 1995




CONCLUSIONS

There was little overlap between the timing of emergence of sawflies and the development of viability in the seeds of two major grass weeds of set-aside land. By the fourth week of May, the majority of *Dolerus* spp. sawfly adults had emerged, but the grass weed seeds were only just becoming viable by this date. Boatman *et al.* (1995), in a separate study of both weeds on Leicestershire set-aside sites, similarly found that although the first viable seeds came from seedheads which had begun to emerge on set-aside in early May, these early seedheads took a long time to mature and no seeds from them germinated until early June. Successful weed control strategies involving cultivation of set-aside to a summer fallow can therefore be carried out in late May without preventing the emergence of the majority of overwintering adult sawflies. This should enable rotational set-aside land to provide areas of refuge where these important chick-food insects can overwinter without high mortality from disturbance and from which they can disperse into the surrounding arable landscape.


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Figure 2.1 Germination of *A. myosuroides* seed collected at different times from set-aside in Hampshire and Leicestershire, summer 1993

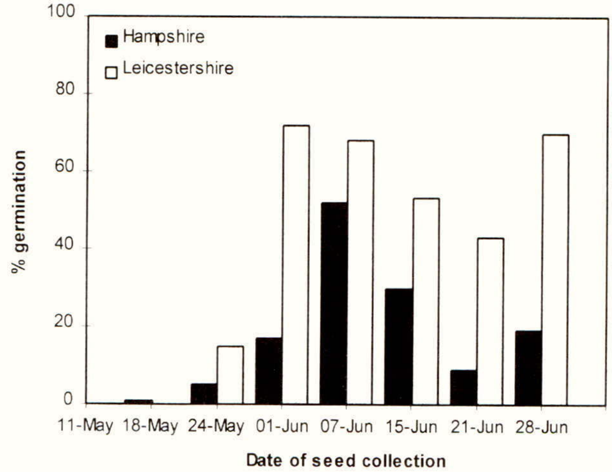
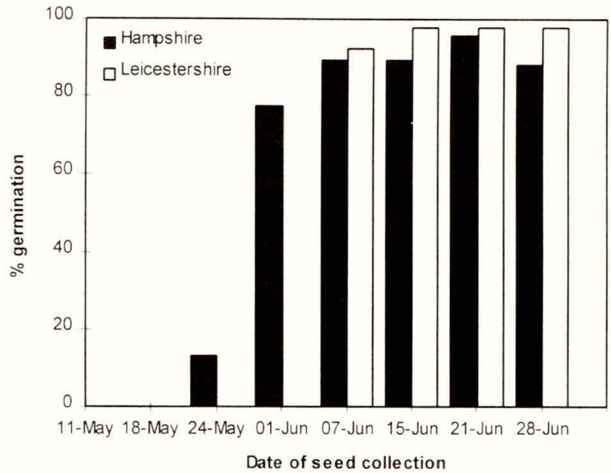



Figure 2.2 Germination of *B. sterilis* seed collected at different times from set-aside in Hampshire and Leicestershire, summer 1993



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# THE EFFECTS OF HERBICIDE USE WITHIN CEREAL HEADLANDS ON THE AVAILABILITY OF FOOD FOR ARABLE BIRDS

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## ABSTRACT

The effect of commonly used cereal herbicides on weeds and their associated insects were assessed by comparing headland plots that received applications of herbicide with plots that were untreated. Direct effects on the plant food of arable birds were studied by comparing differences in the percentage cover and species number of potential seed-bearing weeds between the two treatments. Indirect effects resulting from the removal of food plants on potential invertebrate food groups were also compared. The effect of herbicides on the food availability of arable birds and possible ways to increase available food sources are discussed.

## INTRODUCTION

On farmland, cereals can cover over 60% of the landscape. Within cereal crops, the importance of invertebrates and weeds as food for species of farmland birds have recently been documented (Campbell *et al.*, 1997). Previously, positive significant correlations between invertebrate densities and chick survival in the grey partridge had identified the potential impact of pesticides (Potts, 1986). However, while over the last 20 years several well documented cases of the declining flora and fauna of cereals have been cited due to changes in agricultural practices, studies have generally been confined to the impact of insecticides on non-target predatory invertebrates (Theiling & Croft, 1988, Inglesfield, 1989).

Insects are of varying importance in the diet of adult birds, but are particularly important in determining chick survival. This study examines seven key arthropod groups known to be particularly important in the diet of grey partridge chicks, as well as chicks of pheasant, yellowhammer, whitethroat, dunnock, corn bunting and skylark.

This paper also aims to quantify the direct and indirect effects of commonly used herbicides within the headland area of cereal fields. Headlands have a greater floral and faunal diversity compared to field centres (Wilson, 1989) and are where the first few metres of crop are the preferred brood rearing areas for gamebird chicks (Green, 1984) and many ground-feeding passerines (O'Connor & Shrubb, 1986). By studying headland plots that did or did not receive applications of herbicide, direct effects on the plant food of arable birds and indirect effects on invertebrate bird food groups were compared.

## MATERIALS AND METHODS

The study was carried out in a 40 ha field over three years growing spring wheat in 1988, winter wheat in 1990 and spring barley in 1991, on a mixed arable farm on the Hampshire-Dorset border. Within the field, along one boundary, the headland was sub-divided into eight plots of 100m length to minimise any localised within-field differences. Four sprayed and four unsprayed plots were then randomly placed along the 800m headland.

When the field grew winter wheat, autumn herbicides were applied to the treated plots. No spring applications were applied to the entire field. In spring cereals, herbicides were applied to the whole field with the exception of the untreated plots in late April in wheat and early May in barley. All plots received an application of fungicide during May-June. Herbicides and fungicides were applied at conventional field rates in 200 l water/$ha^{-1}$. No insecticides were applied to any experimental plots. Ten randomly thrown 0.25 $m^2$ quadrats were taken approximately 3m from the field edge in each of the replicated plots in May each year. In each quadrat the percentage ground cover was estimated and the number of grass and broad-leaved species were counted.

Arthropods were sampled within each plot on five dates between May and July each year. On each sampling occasion five samples were collected in the headland, 3m from the field edge using a Dietrick vacuum insect sampler. Each sample comprised five 10 second sucks, each of an area of $0.1m^2$ taken at random. Samples were only taken within the central 50m length of each plot. For analysis mean differences between treatments of seven key arthropod groups, Araneae, Auchenorrhyncha, Heteroptera, caterpillars (Symphyta and Lepidoptera larvae), Chrysomelidae, Curculionidae and Carabidae (Potts, 1986) were carried out. Total Coleoptera and total chick food insects were also analysed.

All analysis was carried out on plot means. The means were transformed using arcsin ($\sqrt{P}/100$) for weed percentage cover and $\log_{10}$ (n+1) for number of weed species and invertebrate groups so as to normalise the data and stabilise the variance.

A two-way ANOVA (year, treatment) with repeated measures was carried out to examine the differences between treatments over the sampling dates using Systat 5. However, due to many significant year:treatment interactions, a one-way ANOVA (treatment) with repeated measures was carried out on individual years and these data will be given in this paper. Statistical differences within Figures 1-6 will be given by; ns = not significant, * = $P< 0.05$, ** = $P< 0.01$, *** = $P< 0.001$.

## RESULTS

For all weed groups in all crops, with the exception of grasses in the spring barley, greater percentage cover scores and species number were found in the unsprayed plots

**Fig. 1. Mean percentage cover and number of weed species in spring wheat, found per ten 0.25m² quadrats taken at 3m into sprayed and unsprayed headlands**

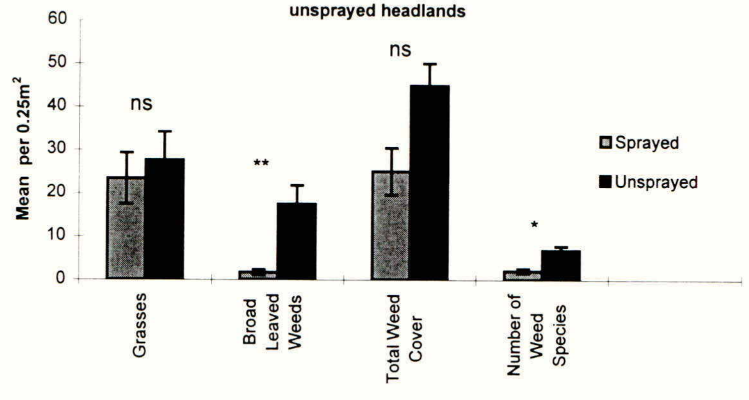



**Fig. 2. Mean percentage cover and number of weed species in winter wheat, found per ten 0.25m² quadrats taken at 3m into sprayed and unsprayed headlands**

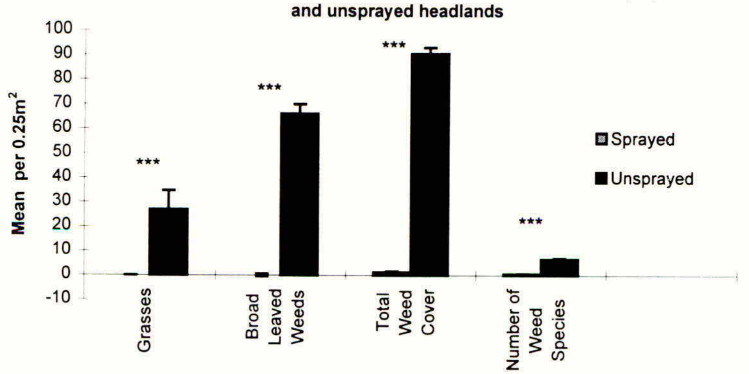



**Fig. 3. Mean percentage cover and number of weed species in spring barley, found per ten 0.25m² quadrats taken at 3m into sprayed and unsprayed headlands**

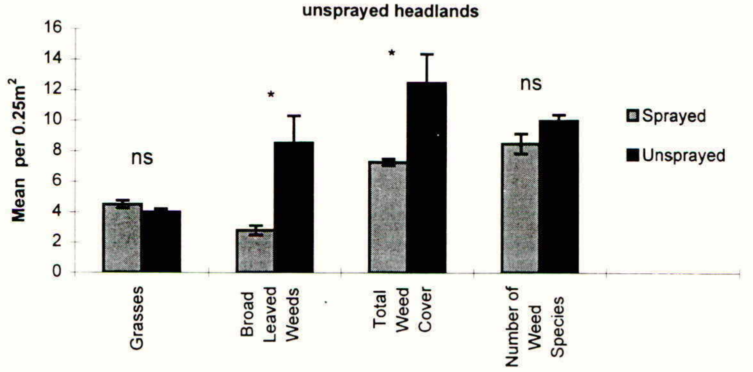


Fig. 4. Mean number of arthropods per $0.5m^2$ at 3m in sprayed and unsprayed spring wheat headlands

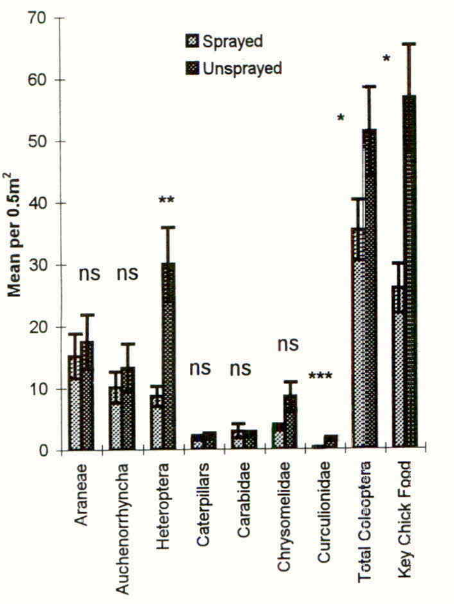



Fig. 5. Mean number of arthropods per $0.5m^2$ at 3m in sprayed and unsprayed winter wheat headlands

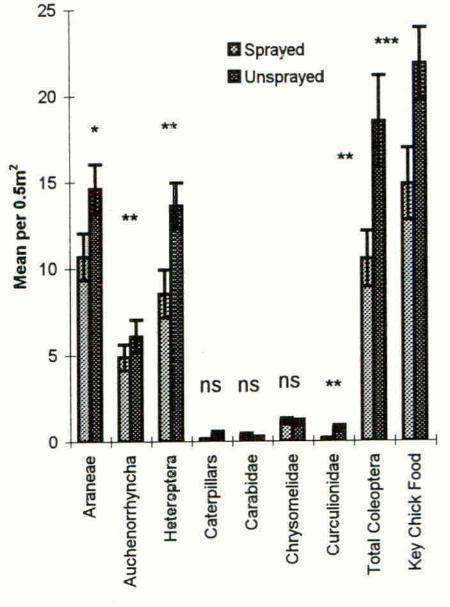
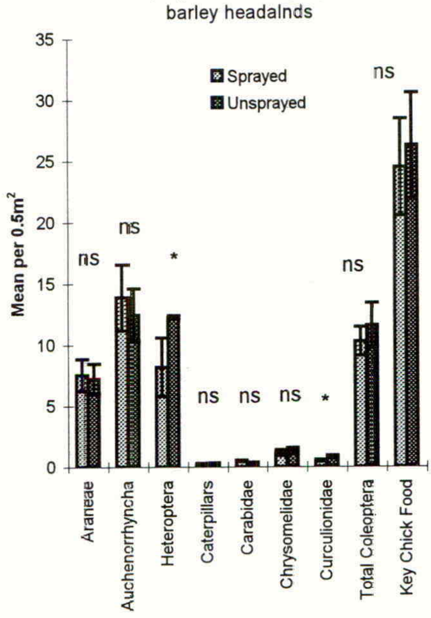



Fig. 6. Mean number of arthropods per $0.5m^2$ at 3m into sprayed and unsprayed spring barley headalnds



compared to those treated with herbicides, with eight out of twelve comparisons being significant (Figs 1-3).

For the arthropods, eight out of nine groups were more numerous in the untreated plots in the spring wheat with four of these comparisons being significant (Fig. 4). In winter wheat eight out of nine groups were more numerous in the untreated plots with six of the comparisons being significant (Fig. 5). In the spring barley six out of nine groups were more numerous in the untreated plots with the difference for Heteroptera and Curculionidae being significant (Fig. 6). In all crops Carabidae were the only group to be more numerous in the treated plots compared to the untreated, however numbers were very low and all differences were non-significant (Figs 4-6).

## DISCUSSION

Weed cover within the three crops (Figs 1-3) clearly demonstrated the significant increase that can occur when herbicides are omitted. Within the winter wheat crop in the absence of autumn applications a dense flora developed in the unsprayed plots while in the treated ones a greatly reduced flora resulted even though no spring herbicides were applied. This was possibly due to the established cereal suppressing new weed germination in the spring. In both spring cereals the removal of a herbicide application did not significantly increase the grass cover, but it did significantly increase the broad-leaved weeds, the most important component of the flora both directly as a food source for birds and indirectly as food and cover for insects. In all years *Poa annua*, a species in which the seeds are an important chick food, comprised over 75% of the grass flora cover, while *Stellaria media* another important food was the most important broad-leaved species in the spring cereals and the second most important in winter wheat after *Papaver rhoeas.* Other important food plants occurring in all fields were *Fallopia convolvulus*, *Polygonum aviculare* and *Chenopodium album.*

In both the spring and winter wheat fields total numbers of chick food insects were significantly increased in the untreated plots. A similar non-significant increase occurred in the spring wheat and the lower arthropod numbers were probably due to the low weed densities compared to the other years (Figs 4-6). Numbers of total Coleoptera, the most important food Order for many bird species also exhibited a similar trend.

Thus, while many key chick food groups occurred in low densities in all fields, the overall increase which was often significant in the untreated compared to sprayed plots demonstrated how reduced herbicide use could benefit farmland birds. Management to increase the availability of suitable chick foods and as a result chick survival would therefore be most profitably carried out within the headland area. Use of methods such as Conservation Headlands (Sotherton, 1991) would maximise the potential effects on the beneficial groups without causing major agronomic problems within the crop. Conservation headlands also have the additional benefit of helping protect the field boundary flora and fauna from pesticide drift (Longley *et al.*, 1997), an area that is an important feeding site for many nesting passerine species such as yellowhammer and whitethroat.

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