SESSION 9A

CROPPING PRACTICES AND BIRDS

Chairman and Session Organiser	DR N D BOATMAN *Allerton Research and Educational Trust, Loddington, UK*
Papers	9A-1 to 9A-4

RESPONSES OF BIRDS TO ORGANIC ARABLE FARMING: MECHANISMS AND EVIDENCE

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ABSTRACT

There are numerous mechanisms by which arable organic farming systems may affect birds. These operate through exclusion of synthetic pesticides and fertilisers, the use of crop rotations with leys, and sympathetic management of non-crop habitats. Exclusion of pesticides and use of mixed farming systems are likely to be of special long-term benefit to several declining farmland birds. Predicted effects of organic farming are predominantly beneficial. This is broadly supported by extensive and intensive studies of birds and their food resources on organic farms in Britain and Denmark. However, this work reveals little about exactly which mechanisms are important. Differences in bird densities between organic and conventional farms may be most pronounced in winter, though breeding skylarks are more abundant on organic than conventionally managed cereals. Even though small in total area, organic farms could have wider effects on populations of granivorous birds by enhancing winter survival. Methodological issues are discussed including pairing of study areas, the difficulty of isolating key mechanisms and the need to build duration of organic management into study design.

INTRODUCTION

British populations of grey partridge (*Perdix perdix*) have been in decline since the 1950s (Potts & Aebischer, 1994). By the early 1980s it was apparent that many other farmland birds were also in decline, including lapwing (*Vanellus vanellus*), turtle dove (*Streptopelia turtur*), skylark (*Alauda arvensis*), tree sparrow (*Passer montanus*), linnet (*Carduelis cannabina*) and corn bunting (*Miliaria calandra*). Agricultural intensification is thought to be a fundamental cause but changes in predation patterns may also be implicated (Fuller *et al.*, 1995). Several key changes in agriculture are likely to have been particularly significant for birds in recent decades. These are the reduction in spring sowing, simplification of rotations, increased use of chemical pesticides and intensification of grassland management achieved mainly through increase in inorganic fertiliser inputs. Detailed understanding is now growing about how agricultural intensification has affected different bird species (e.g. Potts & Aebischer, 1995, Aebischer & Ward, 1997, Wilson *et al.*, in press).

Organic farms exhibit some of the features that have become rare on conventionally managed farmland during the last 30 years. These include (a) rotations incorporating grass leys and legumes, (b) reliance on animal and green manures produced within the farm, rather than on synthetic fertilisers and (c) no use of synthetic pesticides. To some extent, therefore, organic farming reverses recent trends in agricultural intensification. Though it forms a relatively small part of the total farmed area in Britain (50,000 hectares was farmed organically in April 1997) there has been continuing growth in organic farming during the 1990s. It is often claimed that substantial environmental benefits would be derived from a large expansion of organic farming. This paper reviews our understanding of the responses of birds to organic farming systems. The emphasis of this paper is on organic arable systems. Horticultural and grassland systems are not considered specifically, nor are the implications of organic standards for livestock husbandry.

ATTRIBUTES OF ORGANIC SYSTEMS

Two main sets of standards for organic farming in Britain are those of The Soil Association (Soil Association, 1996) and the UK Register of Organic Food Standards (UKROFS, 1992). Organic farms are widely perceived as ones where synthetic pesticides and fertilisers are not used but this definition is far too narrow. Organic and conventional farms differ in several other respects with potential significance for bird populations. Organic farming emphasises the importance of working with natural biological systems, of maintaining soil fertility and structure through rotations, and of self sufficiency in crop and animal residues.

Organic arable systems typically include grass and legume-based leys. Rotations are fundamental to maintaining fertility, soil structure and pest control on most organic farms growing arable crops (Lampkin, 1990). Weed control on arable organic farms is achieved largely through rotations coupled with management of manures and seedbeds and the use of spring-tined harrows or inter-row hoes. Within the arable rotation, an organic farmer will usually make use of a wider range of crops and timing of sowing than his conventional counterpart. Spring-sown cereals are now more frequently grown on organic than most conventional farms (Chamberlain *et al.*, 1995). Therefore, organic farms in arable dominated regions tend to be very different in field composition to surrounding conventional farms. There may also be differences in farm structure. Chamberlain *et al.* (1995) found that the organic farms tended to have smaller fields, more trees in their hedgerows, and a greater proportion of tall, wide hedgerows. This reflects the fact that many organic farmers are sympathetic to the needs of wildlife. The Soil Association and UKROFS standards include specific conservation guidelines.

POTENTIAL RESPONSES OF BIRDS

By combining knowledge about the habitat and food requirements of birds with knowledge about attributes of organic systems one can make several predictions about responses of birds to organic farming systems (Table 1). These predictions are derived from observations of birds within conventional agricultural systems and references are given in the table.

The great majority of predicted effects are beneficial in the sense that they involve increases in food resources or of preferred habitats for a wide range of farmland birds, including many that are in serious decline. There are, however, three aspects of organic farming that could conceivably be viewed as negative for birds. First, field sizes tend to be relatively small and are often enclosed by hedgerows which may make them less attractive to some open field species.

Table 1. Components of organic arable systems, relative to conventionally managed arable systems, that are predicted to affect birds. Wilson *et al.* (1996) was a general source of information on the diets of farmland birds.

WEED, DISEASE AND PEST CONTROL
Organic farms do not use synthetic herbicides, insecticides or molluscicides

Potential mechanisms: (1) Increased availability and abundance of seeds of arable weeds for seed-eating birds. Population effects are most likely to operate through enhanced winter survival but breeding success of turtle dove (*Streptopelia turtur*) and linnet (*Carduelis cannabina*), two ground-feeding seed specialists, may be linked to seed availability. (2) Increased availability and abundance of food for birds feeding on invertebrates resulting from increase in food plants and non-use of insecticides. Reduction of insect chick-food, especially through use of chemical insecticides and herbicides and changes in rotations, has been the principal mechanism of decline in grey partridge (*Perdix perdix*) (Potts, 1997). Similar mechanisms may hold for other declining farmland birds.

Predictions: (1) Concentrations of winter granivores that eat weed seeds are expected to occur on organic farms, especially skylark (*Alauda arvensis*), tree sparrow (*Passer montanus*), greenfinch (*Carduelis chloris*) and linnet. (2) Enhanced breeding production for species that feed nestlings on invertebrates derived from fields and field margins e.g. grey partridge, skylark, whitethroat (*Sylvia communis*), yellowhammer (*Emberiza citrinella*), corn bunting (*Miliaria calandra*).

FERTILISER INPUTS
Organic farms rely on animal and green manures

Potential mechanisms: (1) Enhanced availability and abundance of soil invertebrates, especially earthworms, for ground-feeding birds may arise from use of farmyard manure (Tucker, 1992). (2) Organic crops often consist of sparser vegetation than their conventionally managed counterparts (Moreby & Southway, 1994, Brookes *et al.*, 1995, Wilson *et al.*, in press). Many ground-feeding birds are deterred by tall, dense, lush vegetation e.g. lapwing (*Vanellus vanellus*), skylark, yellow wagtail (*Motacilla flava*). Hence, food availability as well as food abundance (due to some weed tolerance), should be greater in organic than conventional cereal crops for these birds. High rates of inorganic fertiliser can reduce invertebrate numbers (van Wingerden *et al.*, 1992). (3) Tall, fast-growing crops are avoided by nesting skylarks (Wilson *et al.*, in press) and lapwings so organic crops may offer more suitable nest sites.

Predictions: (1) Organic fields should be used more heavily by birds that eat earthworms e.g. lapwing, golden plover (*Pluvialis apricaria*), starling (*Sturnus vulgaris*), fieldfare (*Turdus pilaris*), redwing (*Turdus iliacus*). (2) Birds are more likely to forage within growing organic crops than within their conventional equivalents. (3) Organic crops are likely to support higher densities of nesting lapwings and skylarks.

ROTATIONS AND CROPPING PATTERNS

Organic arable farms are usually mixed systems with rotational grass and relatively high diversity of crops including spring-sown crops

Potential mechanisms: Mixed systems, and therefore organic arable systems, provide a greater range of summer and winter foraging opportunities and nest sites for birds (O'Connor & Shrubb, 1986). Examples follow of how this complexity can affect birds. High crop diversity benefits multi-brooded species or ones with long breeding seasons because they are able to shift nest site or foraging site to exploit seasonally available habitat e.g. skylark (Schläpfer, 1988, Wilson *et al*., in press, Stoate *et al*., in press). Lapwings benefit from systems which have spring cereals adjacent to grass because the former offer preferred nest sites but grass is preferred for chick rearing (Shrubb & Lack, 1991). Leys and spring cereals are especially attractive to nesting skylarks (O'Connor & Shrubb, 1986). Leys may also increase earthworm abundance with benefits for ground-feeding birds (Tucker, 1992). Rotations can uniquely offer undersown spring cereals within which several species forage preferentially e.g. grey partridge (Potts, 1997) and corn bunting (Aebischer & Ward, 1997), because they contain a high abundance of sawfly (Symphyta) larvae. Overwinter stubbles associated with spring cultivation should provide good feeding habitats for seed-eating birds.

Predictions: (1) Species diversity should be higher on organic farms. (2) Densities of breeding skylark, lapwing and grey partridge should tend to be higher on organic than conventional farms. (3) Winter abundance of granivorous species should be higher on organic farms because of stubble availability. (4) Birds feeding on soil invertebrates should be more abundant on organic farms.

BOUNDARY HABITATS AND FARM STRUCTURE

Organic farms tend to have taller, thicker hedges with more trees and fields tend to be smaller

Potential mechanisms: (1) Hedgerow structures on many organic farms will tend to offer better quality habitats for the majority of hedgerow-nesting birds. Structurally complex hedges tend to hold higher densities (e.g. Macdonald & Johnson, 1995). (2) In winter berry-feeding thrushes are likely to find more berries in hedges that are not cut frequently. (3) Small fields surrounded by hedges may be advantageous to small birds feeding in fields which use hedges as cover from predators (e.g. finches and thrushes) but not to those that avoid hedges (e.g. lapwing and skylark).

Predictions: (1) Organic farms will tend to hold higher breeding densities of most hedgerow bird species than conventional farms. (2) Winter numbers of berry-feeding thrushes will be higher on organic than conventional farms. (3) Small field size may tend to negate other potential advantages of organic farming for lapwing and skylark.

On the other hand, these very features will act to make organic farms more attractive to other species. Second, a few crops grown on conventional farms are rather good for birds but are precluded from organic farms because they demand high inputs, notably oilseed rape. Third, where repeated mechanical weeding is undertaken on organic farms this may cause a higher level of disturbance and nest losses for ground-nesting birds compared with weed control by herbicides. The latter issue merits study.

The potential mechanisms by which organic farming benefits birds are numerous and by no means operate only through the exclusion of synthetic pesticides, though the potential gains from this aspect are considerable. The use of rotations in organic arable systems is also highly significant. A compelling case can be made that the demise of mixed farming lies at the root of the farmland bird decline (O'Connor & Shrubb, 1986, Evans, 1997, Potts, 1997). The exact way in which mixed farming affects birds differs from one species to another but key elements are the leys, spring cereals and undersowing. Leys have far more value for farmland birds if undersown in spring cereals than if directly seeded into a prepared seedbed.

The mechanisms in Table 1 differ in the scale on which they may have any positive effect on population sizes. Given the current small scale of organic farming, mechanisms operating on organic farms in the breeding season are likely to have at most only local effects on bird populations. Because many farmland birds are highly gregarious in winter there is a greater possibility that organic farms could have wider population effects through mechanisms that enhance survival outside the breeding season. For this reason, absence of herbicide use, perhaps coupled with presence of stubbles, could be mechanisms by which even small areas of organic farming could benefit farmland bird populations over wider areas.

STUDIES OF BIRDS AND THEIR FOOD RESOURCES ON ORGANIC FARMS

There have been two major comparisons of bird populations on organic and conventional farmland, one in Denmark the other in southern Britain. The Danish study was conducted over four breeding seasons (Christensen *et al.*, 1996). Point counts were used on 31 organic farms with an equivalent number of 'reference points' on adjacent conventionally managed land. Wilcoxon matched pairs tests were apparently used on mean counts pooled from the four years. Of the 57 species occurring at >10% of points, 31 were significantly ($P<0.05$) more abundant on organic and three significantly more abundant on the conventional points. These tests do not take year effects into account. Nonetheless, the pooled counts for 50 of the 57 species (88%) were higher on the organic farms (sign test $P<0.0001$). Petersen (1994) provides an additional analysis of the Danish data for 10 species in which selections of points are used which are more closely matched by habitat type. The resulting 'corrected' abundances of these species on conventional relative to organic farms were: lapwing 46.6%, skylark 49.8%, swallow (*Hirundo rustica*) 42.9%, white wagtail (*Motacilla alba*) 95.7%, whitethroat (*Sylvia communis*) 71.4%, magpie (*Pica pica*) 108.2%, starling (*Sturnus vulgaris*) 48.1%, linnet 47.2%, corn bunting 42.7%, yellowhammer (*Emberiza citrinella*) 64.8%. Territory mapping results are also given for a pair of organic and conventional farms by Christensen *et al.* (1996). Total breeding bird density was approximately twice as high on the organic farm in each of four years and the majority of species were more abundant on the organic farm. Skylark, the most abundant species, was at least twice as abundant on the organic farm in each year. A winter study of yellowhammers in Denmark found effects of boundary type, crop type and organic management on the species distribution (Petersen, 1994). There was a particular preference for organic stubbles but densities were also higher in organic than conventional leys.

The British study was conducted in three breeding seasons and two winters and used mapping methods on paired organic and conventional farms (Chamberlain *et al.*, 1995). Densities were calculated separately for field boundaries and for fields in each of three seasons: spring (breeding), early winter, late winter. In the majority of species studied, density was consistently higher on organic farms. In all season/habitat samples a larger proportion of species attained higher densities on organic than conventional farms. This preponderance of higher densities on organic farms was statistically significant (sign tests, $P<0.05$) in the majority of season/habitat samples. Density differences in boundaries were more marked in winter than summer. All significant differences in boundary densities of individual species (determined by distribution free randomisation) were in favour of higher densities on organic farms. Winter usage of organic fields was also generally greater, but two species (lapwing and fieldfare *Turdus pilaris*) were significantly more abundant in conventional fields. Both this extensive study and an intensive study (Wilson *et al.*, in press) show that breeding densities of skylarks tend to be higher on organic than conventional farms. Subsequent analyses of the data at the whole farm level (Chamberlain *et al.*, submitted) also show a strong preponderance of higher species densities on organic farms. Numbers of species showing significant differences were, however, considerably reduced but all were in favour of organic farms. Overall density tended to be greater on organic than conventional farms but there were no clear differences in species diversity. Bird communities at the whole farm level were examined in relation to habitat characteristics and farm management using canonical correspondence analysis (CCA). Organic management was found to be one of several factors strongly influencing species gradients, other main factors being boundary characteristics, cover of winter cereals, cover of stubble and farm area. Granivorous species, for example tree sparrow, tended to be most strongly associated with organic management.

There are two relevant studies of breeding productivity. In Denmark, yellowhammer brood sizes, measured as family groups in August, were recorded over three years and found to be significantly higher in organic fields in each year. In Britain, Wilson *et al.* (in press) found higher rates of daily and overall nest survival in organic cereals than in conventional cereals but sample sizes were too small to assess clear statistical significance.

There have been three comparisons of weed and invertebrate abundance in organic and conventional fields. First, Brookes *et al.*, (1995) found that cover of weeds was higher in organic than conventional cereals. Broadleaved weeds dominated in organic cereals and grasses in conventional cereals. This difference was reflected in the composition of soil surface seeds but there were no differences in overall seed abundance between systems. More plants capable of producing suitable sized seeds for skylarks were present in organic fields. Total numbers of invertebrates trapped by vacuum sampling and soil cores did not differ between organic and conventional cereals. However, some invertebrate groups were more abundant in organic cereals and some in conventional fields. Second, similar results were obtained by Moreby *et al.* (1994) for winter wheat. They found higher cover of broadleaved weeds and larger numbers of broadleaved species in the organic fields. Again, some invertebrate groups were significantly more abundant in organic fields and some in conventional fields. The guild of important gamebird chick-food insects tended to be more abundant in organic fields but not significantly so. Third, work in Denmark, summarised by Petersen (1994), found higher biomass of both weeds and arthropods in organic cereals.

Brookes *et al.* (1995) found higher densities of immature Diptera, including leatherjackets, on organic leys than in cereal crops. They also found higher densities of earthworms on organic than conventional cereal fields which is consistent with the results of a more recent study (Neale, 1996). Long-term leys appear to have the effect of enhancing earthworm biomass in the immediately following cereal crop (Neale, 1996).

METHODOLOGICAL ISSUES

Both the Danish and British studies attempted to control for major differences in non-crop habitat but residual differences remained which undoubtedly affected recorded bird densities. Pairing of organic and conventional farms will always prove problematic but to some extent the issue is philosphical rather than scientific as it hinges on how one defines organic farming. Criticisms of pairing procedures appear often to be rooted in the belief that organic systems are primarily defined in terms of non-use of synthetic pesticides. At the whole farm level, non-crop habitat differences are inevitable because conservation is intrinsic to organic farming, but more dependent on the interest of individual farmers in conventional systems. At the level of the cropped land, differences in crop type are also unavoidable because of the rotational basis of organic farming. It is, therefore, entirely valid to ask what are the effects of organic farming at the 'whole farm' or 'whole cropped area' scales.

Many specific hypotheses could be derived from the information in Table 1 but not all would be easy to test because some groups of birds are affected by multiple mechanisms. While it is desirable to establish the effects of pesticide exclusion, this cannot be achieved through large-scale surveys of the kind undertaken to date. Nor can it be achieved simply by comparing the same crops under organic and conventional management because it is necessary to control for preceding crops and fertiliser inputs. Isolation of the effects of individual components, such as pesticides, requires experimental manipulation of crop management. This may be virtually impossible to achieve satisfactorily for birds in a direct way because large-scale replicates of various treatments would be needed to obtain adequate samples. Experiments could be more readily undertaken to examine responses of important avian foods to individual components of organic management. Even this may prove difficult because a clear distinction must be drawn between short-term and long-term effects of organic farming on food resources. Dessaint *et al.* (1997) have shown that seed density in unsprayed fields increases slowly. There may be little change in the seed bank for several years. This may have been a principal source of variation in bird populations among the organic farms studied by Chamberlain *et al.* (1995).

CONCLUSIONS

The results of the comparisons of bird populations on Danish and British organic and conventional farmland should be regarded as indicative. The evidence is that bird populations are generally higher on organic farms and that there are 'whole system' benefits to birds from organic farming. The studies conducted to date, however, tell us little about exactly which of the many potential mechanisms (Table 1) underpin these differences. Nonetheless, there are reasons to believe that substantial benefits are derived from the cropping systems used on organic farms, rather than simply from differences in non-crop habitat such as hedgerow structure. First, the British studies indicate that among the birds likely to benefit most from organic farming are several species primarily dependent on the fields rather than on boundary habitats. Second, Wilson *et al.* (in press) show that breeding skylark densities remained higher on organic than conventional cereals when differences in vegetation structure, field boundary and field area had been controlled. Third, higher quantities of some food resources, notably weed seeds and earthworms, occur in organic than conventional cereals, though findings concerning arthropod abundance in cereal crops are less clear.

Future work should focus more on selected groups of birds, on quantifying their food resources and on the management factors that affect these foods. Winter granivorous birds are an obvious target because (a) it appears that they do make preferential use of organic farms, (b) they are particularly likely to benefit from lack of herbicide use and presence of stubbles, (c) organic farms may have considerable potential to affect population levels through enhancing survival of winter flocking species. Key questions are how much weed seed makes a difference for these birds and what determines seed quantity and availability? Duration of organic management should be a key design factor for future studies. The value of organic farms for birds also needs to be set in a landscape context. For example, how do organic farms compare to rotational set-aside which is also selected by wintering seed-eating birds (Evans, 1997)? Despite its current small scale, organic farming has a strong conservation advantage over set-aside in that it has the long-term commitment of those involved in it. Furthermore it would appear that organic farming offers a range of additional ‘whole system’ potential advantages to birds.

Organic farming is not static. Two areas of possible change are the development of more efficient methods of non-chemical weed control and the emergence of stockless organic systems which would be a pre-requisite for more arable farmers converting to organic management. The former would clearly be undesirable if it resulted in weeds being reduced to levels that had no discernible benefits for wildlife. This is unlikely to happen if the current organic philosophy is maintained which is to control weed growth but not to eliminate it completely (Lampkin, 1990). There is no sign that organic stockless systems will be developed on a large scale. However, stockless systems that maintained rotational undersown grassland could still be valuable wildlife habitats.

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SEED-EATERS, STUBBLE FIELDS AND SET-ASIDE

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ABSTRACT

One of the most fundamental changes in cropping practice since the early 1960's has been the development of hardy winter-sown varieties of cereal and the consequent shift in the timing of tillage from spring to autumn. This has resulted in the progressive reduction in the number of cereal stubble fields left unploughed for all or part of the winter. Fourteen species of farmland bird have declined by more than 50% between 1969 and 1994; over half of these eat seed in the winter. The importance of winter stubble fields as a potential food source for these species is reviewed. Set-aside appeared on a wide scale in arable farmland in the UK in 1992 when it became a condition for receipt of Arable Area Payments. A cereal field put into rotational set-aside with a green cover established by natural regeneration becomes a winter stubble. The use made of set-aside by wintering birds and its potential conservation value to declining farmland birds is discussed.

INTRODUCTION

The recent, severe declines in populations of many species of farmland bird in the UK have been well publicised (Fuller *et al.*, 1995, Baillie, in press). Given the similarity in the timing of many of the population trends observed (Campbell *et al.*, 1997) and the ecology of those species in decline (Evans, 1996, Baillie in press) it would be surprising if the causes of the declines did not share a common source. The rapid evolution of farming practices and techniques since the end of the Second World War and the sweeping effect this process has had on the agricultural landscape has been well documented (Briggs & Courtney, 1985, O'Connor & Shrubb, 1986). Increasingly research has concentrated on looking for both temporal and spatial correlations between bird population declines and farming changes and direct ecological evidence of a link. Changes in farming practice can affect birds dependent on farmland in many ways but these have been simplified (Evans *et al.*, 1995) as reducing food availability for adults and for chicks and decreasing nest site availability. One fundamental change has been the development of varieties of cereal, primarily barley, which are both hardier and higher yielding than their predecessors; this has precipitated a switch in the timing of tillage from spring to autumn. Consequently there has been a change in the crop rotations used on most arable enterprises and in particular a massive reduction in the area of cereal stubble (the uncultivated aftermath of harvest) left for part or all of the winter. Stubble fields from traditionally managed cereals used to be rich in both spilt grain and arable 'weeds' and therefore potentially important food sources for seed-eating farmland birds. Over a decade ago the loss of stubble fields as a result of the change in the timing of tillage was identified as a potential problem facing the farming avifauna (O'Connor & Shrubb, 1986). It may be that the quality of the remaining stubbles has been vastly reduced as a result of the indirect effects of herbicides on the preceding crop (Campbell *et al.*, 1997). Here I review several recent studies of farmland birds and assess how detrimental this switch has been.

Farmland bird species in decline

In a recent review of avian conservation priories in the UK, Channel Islands and the Isle of Man Gibbons *et al.*, (1997) identified 36 species considered to be of High Conservation Concern. Of these, 14 are partly or completely dependant on farmland habitats and qualify for the 'Red List' because their numbers have declined by more than 50% in the last 25 years (Gibbons *et al.*, 1996). Of these 14, nine are resident in the UK of which eight feed predominantly on seed during the winter and are therefore likely to have suffered from the loss of over winter stubble fields (Table 1). In signing the Biodiversity Convention in Rio in 1992 the Prime Minister made a firm commitment to stopping the loss of wildlife from the UK. This will be achieved through the Biodiversity Action Plan (BAP) process which has identified farmland as extremely important for Biodiversity and agricultural intensification as a severe threat to that resource (Anon. 1995). Indeed Species BAPs have already been prepared for grey partridge, skylark and song thrush.

Table 1. Resident farmland bird species of High Conservation Concern in the UK

1. Decline on farmland, 1969-94 from British Trust for Ornithology's Common Birds Census

2. Decline in occupied 10 km squares, 1968-72/1988-91 (Gibbons *et al.*, 1993)

3. * = seeds form predominant part of winter diet

Species		Decline in numbers[1]	Decline in Range[2]	Eats seeds in winter[3]
Grey partridge	(*Perdix perdix*)	82%	19%	*
Skylark	(*Alauda arvensis*)	58%	2%	*
Songthrush	(*Turdus philomelos*)	73%	2%	
Tree sparrow	(*Passer montanus*)	89%	20%	*
Linnet	(*Acanthis cannabina*)	52%	5%	*
Bullfinch	(*Pyrrhula pyrrhula*)	73%	7%	*
Cirl bunting	(*Emberiza cirlus*)	no data	83%	*
Reed bunting	(*E. schoeniclus*)	62%	12%	*
Corn bunting	(*Miliaria calandra*)	>80%	32%	*

RESEARCH REVIEW

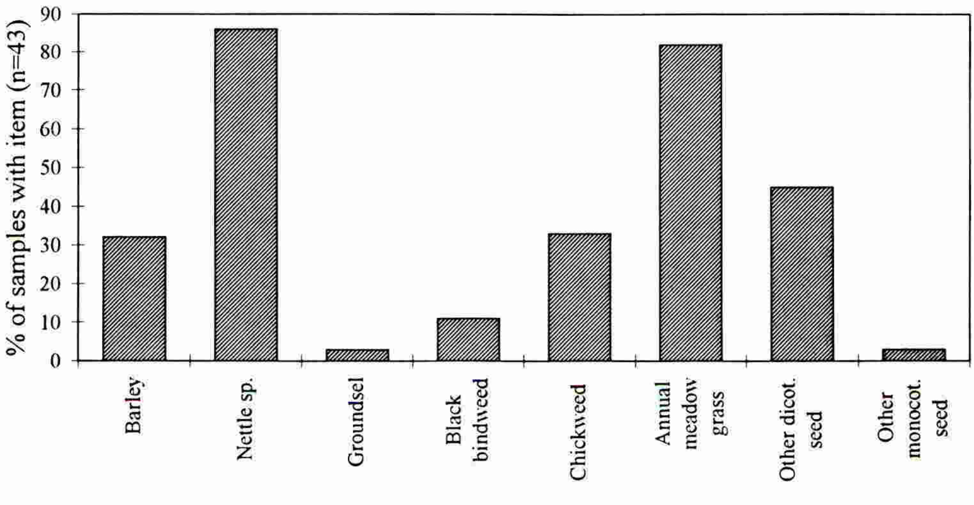
There have been three types of studies of farmland birds carried out to ascertain the causes of their declines. These are single species (autecological) studies, single species surveys and studies of bird distribution with respect to crop type on individual farms.

Autecological studies

The ecology of two species in Table 1, cirl bunting and grey partridge has been studied in detail although there exist ongoing studies of songthrush, skylark, linnet and corn bunting.

Cirl buntings were common and widespread throughout southern England in the mid 1930's. By the late 1960's gaps had begun to appear in their former range and the population crashed in the 1970's so that by 1989 only 118 pairs remained, the vast majority of which were confined to south Devon (Sitters, 1985, Evans, 1992). The Royal Society for the Protection of Birds (RSPB) studied the ecology of the species, starting in 1988 with the aim of identifying the causes of the decline. In winter all fields were searched approximately every fortnight at two study sites (each *c.* 150 ha) over three winters (Evans & Smith, 1994). At both sites in all three winters far more birds were found on stubble fields than the relative availability of that habitat would suggest. At one site birds were consistently to be found on one individual field (the only stubble on the site) which had been abandoned after being sold for building development. At the other site birds were predictable in their location within a winter but followed the stubble as it moved around the study site with the arable rotation. In a wider scale survey 41 randomly chosen stubble fields within the cirl buntings range were searched for birds. The number of dicotyledonous plants along a 10 m transect were counted. There was a significant positive relationship between field 'weediness' measured by this method and the number of foraging cirl buntings. Dissection of faecal samples under a binocular microscope revealed identifiable fragments of seed testa from arable flora including chickweed (*Stellaria media*), black bindweed (*Fallopia convolvulus*), groundsel (*Senecio vulgaris*), nettle species and annual meadow grass (*Poa annua*) in addition to barley grain.

Figure 1. Plant component of diet of adult cirl buntings foraging on stubble fields during winter as determined from analysis of faecal samples



The results of this study showed that not only were cirl buntings feeding exclusively on cereal stubble fields during the winter, but that they were relying on seed from the arable flora in addition to spilt grain. Analysis of Ministry of Agriculture, Fisheries and Food (MAFF) June census statistics showed that over the period 1979-1992 the proportion of cereals sown in the spring in Devon remained at about twice that of the mean of the 12 counties occupied by cirl buntings at the peak of their range, although it declined from *c.* 60% to *c.* 25% during this period.

The grey partridge is the best studied farmland bird as a result of the Game Conservancy Trust's long running project based on the South Downs. In his monograph on the species Potts (1986) describes how partridges feed on the spilt grain and weed seed left on stubbles after cereal harvest. In particular he mentions black bindweed as the most preferred seed (comparing the incidence in the diet and on stubble fields). He also mentions knotgrass (*Polygonum aviculare*) and hemp nettle (*Galeopsis tetrahit*) as important dietary components. Potts points out that not only has the amount of available stubble decreased but that the quality of that which remains has been impoverished as a result both of the improved mechanisation of combine harvesters which now spill less grain and ever more efficient weed control. For instance the amount of *Polygonum* spp. seed in partridge crops fell from 31% of total food in the 1930's to 2% in 1977 (Potts 1986). Moreover in 1971 30% of cereal fields on the South Downs contained black bindweed; this had fallen to 4% by 1982. Despite these changes in winter habitat Potts was unable to detect any effect on winter mortality in the grey partridge; in this species increased chick mortality as a result of loss of insect food due to pesticide application appeared to be a much more important factor.

Single species surveys

Of the species in Table 1 only corn bunting has been the subject of a published national winter survey (although a similar approach has been recently carried out on skylark by the British Trust for Ornithology). In winter 1992/93 volunteers visited 1313 tetrads (2 km x 2 km squares) throughout the range of the corn bunting in Britain (Donald & Evans, 1994). Of these 889 were selected at random, the others on the basis that local knowledge indicated that they were likely to hold corn buntings. Observers were asked to search each tetrad once, recording numbers of birds seen and aspects of habitat including crop type. Stubble fields were included in the habitat types recorded and divided into 'weedy' (where the ground cover of weeds was estimated at > 20%) and 'clean' (< 20%). The species was located in 160 tetrads and a total of 222 flocks (including single birds) or 2909 individuals were counted. Fifty per cent of flocks (60% of individuals) were found on stubble fields with 'weedy' stubbles holding approximately twice as many birds as 'clean'. When habitat used by corn buntings was compared with that available only three crop types, 'weedy' stubble, 'clean' stubble and unimproved grassland were preferred whereas winter cereals and improved grass were avoided. Randomly selected tetrads in areas which had retained corn buntings had more 'weedy' stubble than those which had lost the species between 1968-72 and 1988-91 (Gibbons *et al.*, 1993).

Distribution studies

There have been two major studies of the winter distribution of seed-eating birds on farmland. Both used similar methods; walking transects across every field which were sufficiently close to each other so as to flush all feeding birds (this varied with crop type) and then relating distribution to availability using resampling methods applied to the actual bird counts. The study design differed, however, with the emphasis of the projects. The first (Wilson *et al.*, 1996) made 12 visits in the winter of 1994/95 to each of 5 study areas in Oxfordshire; two of the farms were managed according to the Soil Associations organic standards, the other three were farmed conventionally. The second study (Evans *et al.*, in press) concentrated on comparing use made of set-aside with other field types, and three or four visits were made to 40 farms in each of the two winters 1993/94 and 1994/95. Half the farms were in East Anglia and thus predominantly arable, the rest in Devon where farming enterprises tend to mix arable and livestock. These two studies obtained data for 6 of the species in Table 1.

Table 2. Results of farmland bird distribution studies
Study 1 = Wilson *et al.*, (1996), 2 = Evans *et al.*, (in press)
+ = significant preference, - = significant avoidance, nd = no data available, no symbol indicates that the crop was used in proportion to its availability by that species.

	Stubble		Winter cereal		Grazed grass		Set-aside	
Study	1	2	1	2	1	2	1	2
Grey partridge	+	+		-	-		nd	+
Skylark	+	+	-	-	-	-	nd	+
Song thrush			-			-	nd	
Linnet	+	+	-	-	-	-	nd	+
Reed bunting	+	nd	-	nd	-	nd	nd	nd
Cirl bunting	nd	+	nd	-	nd	-	nd	+

The results of these two studies (Table 2) show that five of the six species covered (grey partridge, skylark, linnet, reed bunting and cirl bunting) showed a significant preference for foraging on stubble fields over the other major field types. Winter cereals were avoided by most species. The first study found no difference in the pattern of habitat selection between stubble fields resulting from organically managed and conventionally managed cereals. The second study showed also that, not surprisingly, the pattern of selection for set-aside among the species was the same as that for stubble, suggesting that it can indeed replace this important habitat element in the farmland environment.

CONCLUSIONS

In the past five years the continuing decline in farmland bird populations has been recognised as one of the greatest problems facing conservationists in the UK. Studies of farmland bird ecology have proliferated as a result. Of the nine resident species which declined in excess of 50% between 1969 and 1994, sufficient data have been collected to assess the importance of stubble fields for seven (Table 3); tree sparrow and bullfinch require further work and have not been included in this table. Of these it can be concluded that stubble fields form an important winter food source for six; the only exception being song thrush. This is not surprising as all are either obligate seed-eaters or species which feed mainly on seed during the winter. Stubble fields provide a rich source of seed (although the amount of seed from arable flora and spilt grain on stubble fields has declined as described earlier) in a habitat which is open enough to allow birds to forage unimpeded yet still provides some cover. It may have become increasingly important as other seed sources such as stack yards and threshing yards and accessible feed for livestock have become increasingly scarce. There is little doubt that the area of stubble fields left for part or all of the winter has declined since the 1960s as the timing of tillage has shifted towards the autumn. Unfortunately there are no data to describe the magnitude of this loss. Undoubtedly it will have varied regionally with soil type. Whilst set-aside was designed as a production control mechanism and not as agri-environment scheme it may well have been of huge benefit to declining farmland birds by replacing a seed source in the environment. The value of set-aside land will of course depend upon how it is managed. In order to provide food sources for seed-eating birds over winter the RSPB recommend the use of rotational set-aside with a green cover established by natural regeneration rather than by sowing. Wildbird cover is another beneficial option but further research is needed on which seed mixtures to grow for which species of bird. Options involving industrial cropping and establishment of long-term grass are of little value as a winter food source for seed-eating birds. Whatever the benefits that have accrued so far set-aside is not the solution to the conservation problem of declining farmland birds. Since 1992/93 the area of land in the scheme has decreased by two-thirds and the proportion of set-aside in our preferred option has also declined. What is needed is an option under the agri-environment scheme to compensate farmers nationwide for leaving a proportion of their cereal stubbles fallow over winter. Hopefully MAFF's new Pilot Arable Stewardship Scheme (ASS) will eventually do just that, but until such a scheme is in place it is vital that set-aside is retained and that farmers are provided with the advice they need to manage it in the best way for wildlife. Recent proposals for further reform of the Common Agricultural Policy by the European Commission (Agenda 2000) include the abolition of set-aside as a policy instrument. If this should occur there will be an urgent need to extend the ASS nationwide.

Table 3. Summary of research results regarding the importance of stubble fields as winter food sources.
Y = evidence that stubble fields are important
N = evidence that stubble fields are not important
() = expected conclusion from ongoing study

Species	Autecological studies	Single species surveys	Distribution studies
Grey partridge	Y		Y
Skylark	(Y)	(Y)	Y
Song thrush	(N)		N
Linnet			Y
Cirl bunting	Y		Y
Reed bunting			Y
Corn bunting	(Y)	Y	

All the research described is open to the criticism that whilst it provides circumstantial evidence of the importance of stubble fields to seed-eating birds it cannot prove a causal link between the decline in availability of stubble fields and the decline in bird populations. To do so it would be necessary to show a corresponding increase in mortality as a result of starvation; this is simply not possible for any species other than grey partridge because the only reliable method would be through the recovery of individually marked birds and there are insufficient ringing data available to do this. Two pieces of evidence do, however, exist which contribute further circumstantial evidence suggesting that loss of stubble fields may have contributed to population declines. The corn bunting survey described earlier (Donald & Evans, 1994) demonstrated that tetrads in 10 km squares which had lost breeding corn buntings between 1968-72 and 1988-91 (Gibbons *et al.*, 1993) had less stubble in winter than those in 10 km squares which had retained their birds. Since the RSPB study discovered that cirl buntings in winter foraged almost exclusively on stubble fields, the availability of stubbles has been increased (Evans, 1997). RSPB initially paid for six farmers to leave some stubble overwinter; four of these sites were used by a total of 77 cirl buntings. Then in 1992 set-aside became a requirement for receipt of Arable Area Payments and thus became widespread; the distribution study described above (Evans *et al.*, in press) demonstrated that cirl buntings used fallow created under set-aside. Finally Countryside Stewardship provided a further mechanism. Over 50 farmers have now entered into the scheme and adopted 10 year management plans devised with the help of an RSPB project officer. These plans include the provision of winter stubble annually. Over 1,200 ha of land are now covered by Stewardship agreements, supporting approximately 35% of the UK population of cirl buntings. Since this increase in the availability of stubble fields the cirl bunting population has shown a partial recovery from between 118-132 pairs in 1988 to 373 in 1995. It remains to be seen whether forthcoming analyses of national census data indicate recoveries or even ameliorations of rates of decline in species such as linnet and skylark.

It is important to remember that the loss of stubble fields is only one of a suite of inter-connected changes in farming practice many of which are likely to have had a detrimental effect on the habitat of farmland birds and thus also on their populations. For instance the loss of insect larvae from farmland due to the indirect effects of pesticides is thought to be one of the main reasons behind the decline of the grey partridge (Potts, 1986) and cannot be ruled out as a major factor in the population declines of skylark, song thrush, tree sparrow, linnet, bullfinch and reed bunting (Campbell *et al.*, 1997) . Loss of nesting sites through loss of spring tillage (for ground nesters) and hedgerow removal may also have caused problems. It is important to address all these factors, not just provision of stubble and this is precisely what MAFF's Pilot Arable Stewardship Scheme is designed to do. It is likely that the major cause of the severe declines we have witnessed in farmland birds will vary between species. Indeed for some species the changes in their environment have been so catastrophic that determining which factor has had the greatest effect may not be relevant. It is clear, however, that without an adequately funded, integrated scheme of prescriptions such as the ASS we cannot hope to see an improvement in our farmland wildlife; without changes in current cropping practice, however achieved, the Government will fail to deliver its promises to stop the declines in Biodiversity in the UK.

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EFFECTS OF CROPPING PRACTICES ON DECLINING FARMLAND BIRDS DURING THE BREEDING SEASON

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ABSTRACT

Twenty-four species of our farmland birds have declined in abundance over the last few decades, during a period of agricultural intensification. Studies of the grey partridge and of four other bird species have several themes in common: loss of nesting and foraging habitat, drop in numbers of chick-food invertebrates, susceptibility to nest predation. Densities of birds and of their chick-food items have suffered from the polarisation of agriculture towards intensive arable or intensive livestock farming, and changes in practices regarding grassland management, timing of sowing and pesticide use. Where such cropping practices are favourable, for example on traditional mixed arable farms, bird and insect densities can be high. Methods like Conservation Headlands, Beetle Banks and set-aside allow certain aspects of such farming to be reproduced on intensive farms with little economic penalty and considerable conservation benefits to plants, insects and ultimately birds.

INTRODUCTION

Out of a total of 28 species of birds that have been classified as farmland birds (Gibbons *et al.*, 1993), 24 or 86% have declined in abundance in Britain between 1970 and 1990 (Fuller *et al.*, 1995). Many of these declines began during the mid-1970s, at a time of rapid agricultural change. In general terms, arable agriculture has intensified at the expense of mixed farming: spring-sown cereals have to a large extent been replaced by autumn-sown crops, rotational grass leys have all but disappeared, fields have been enlarged by boundary removal, and chemical inputs of fertilisers, pesticides and growth regulators have increased (Jenkins, 1984, Potts, 1986, Aebischer, 1991). It is likely that some at least of these factors are implicated in the observed declines of farmland birds.

AGRICULTURE AND BREEDING BIRD DENSITIES ON FARMLAND

Evidence exists that changes in agriculture have played a role in the declines in the breeding numbers of at least five birds typical of arable and mixed farmland: the grey partridge (*Perdix perdix*), the lapwing (*Vanellus vanellus*), the skylark (*Alauda arvensis*), the corn bunting (*Miliaria calandra*), and the cirl bunting (*Emberiza cirlus*). I review each of these species below, indicating the extent of the declines and the agricultural practices that have been implicated in them, concentrating on those that operate during the breeding season.

Grey partridge

The grey partridge is a farmland bird that had already declined in Britain by the 1960s, and whose numbers have now dropped by over 80% (Potts, 1986). A study to investigate the causes of its decline was launched in 1968 by The Game Conservancy Trust. It has developed into one of the longest ecological studies of a farmland bird in the world, and as a result the grey partridge is one of the best understood of the farmland species. Research has shown that there are three main causes for its decline: increased predation during the breeding season, loss of nesting cover and a reduction in chick survival during the first six weeks of life (Potts, 1980, Potts, 1986). The last two factors are both a function of changes in farming practice. Partridges nest on the ground, seeking out slightly elevated nest locations, such as hedge banks, and tall grassy vegetation (Rands, 1986). The loss of nesting cover results, first, from the removal of field boundaries (hedgerows, banks, grassy margins) as fields are enlarged for more efficient use of machinery (Jenkins, 1984). Second, what cover remains is often rendered unsuitable for nesting, as it is cut or treated with herbicide to prevent contamination of the crop by invasive weeds (Boatman, 1992), and suffers from fertiliser and pesticide drift (Longley *et al.*, 1997).

Grey partridge chicks leave the nest with their parents shortly after hatching, and spent 97% of their time inside cereal crops, close to the margin (Green, 1984). They forage for themselves, and their diet during the first two weeks comprises almost entirely insects, a rich source of protein (Potts, 1986). Chick survival during this early period is strongly dependent on the availability of certain preferred insect groups within the fields and on the proportion of certain taxa in the diet. Insects that seem particularly important are phytophagous ones such as caterpillars of Symphyta (sawflies) and Lepidoptera (butterflies and moths), Chrysomelidae (leaf beetles) and Curculionidae (weevils). The reduction in chick survival began with the introduction of herbicides in the early 1950s, which destroyed many of the host plants of the chick-food insects and probably halved the abundance of invertebrates within cereals (Southwood & Cross, 1969). Between the 1950s and the 1970s, average chick survival rates fell from over 40% to around 30% (Potts, 1986). More recently, the intensive use of broad-spectrum insecticides has also been found to reduce partridge chick survival, by about a third on average (Aebischer & Potts, 1997). An independent review (Campbell *et al.*, 1997) concluded that the grey partridge provides the best evidence for any bird species of an indirect effect of pesticides.

Lapwing

The lapwing is another bird that nests almost exclusively on farmland. Its breeding abundance in Britain has declined by about 60% since 1960, and the potential effects of agricultural change have been reviewed by Hudson *et al.* (1994). They have highlighted three interconnected changes in agricultural practices that have affected lapwing abundance: the switch from spring-sown to autumn-sown cereals, the improvement of pasture, and the phasing out of mixed rotational farming. Lapwings prefer to nest on bare ploughed ground or bare patches within sprouting arable crops (Shrubb, 1990). On land used for autumn-sown crops, the crop is usually too tall by the beginning of the nesting season, in April, to be suitable. The widespread switch from spring-sown cereals to the more profitable autumn-sown ones has therefore reduced potential nesting habitat considerably. Moreover, the availability of the invertebrate food eaten by adults and chicks is much lower on arable land than on grassland, and chicks hatching on arable are preferentially led onto pastures to fledge (Galbraith, 1988). The increasing polarisation of agriculture from mixed arable to either pure arable or pure livestock has exacerbated the situation not only because crops are more likely to be spring-sown in mixed farming systems (to provide stock feed), but also because it produces the juxtaposition of arable and pasture that is so beneficial to lapwing broods. For lapwings nesting on pasture, improvements through drainage, reseeding and fertilisation have led to higher stocking rates of sheep and cattle, resulting in increased nest losses through trampling and livestock-caused desertions, and lower nesting densities (Baines, 1988, Shrubb, 1990). Where cattle are not grazed, traditional hay-cutting has been replaced by frequent silage-cutting, which again causes the loss of many nests.

Skylark

Although the distribution of the skylark across Britain has changed little over the last thirty years, it has declined in numbers by over 50% since 1968 (Fuller *et al.*, 1995). Probable causes for the decline are the switch from spring-sown to autumn-sown cereals, the disappearance of mixed rotational farming, and poor breeding success on intensive arable land. The skylark requires an open landscape, and nests on the ground in low vegetation on arable and grass fields. Like the lapwing, the change from spring-sown to autumn-sown crops means that on arable land, the crop may be too tall to serve as nesting habitat (Schläpfer, 1988). Under a mixed farming system, first-year leys are particularly attractive as nesting areas, as the sward is still open and offers good foraging opportunities as well as nesting sites. Parents feed their chicks in the nest after hatching, and the chick diet consists almost exclusively of invertebrates (Jenny, 1990, Poulsen & Aebischer, 1995). Food availability is lower in purely arable areas than in areas of mixed farming; without access to invertebrate-rich pastures, parents may be forced to forage outside the limits of their territories and chicks have been recorded as dying from starvation (Jenny, 1990). Productivity has been found to be especially low in winter wheat (Evans *et al.*, 1995). On pasture, nesting skylarks face the same kind of problems as lapwings, in that the higher stocking rates on improved grassland are likely to increase nest losses through trampling. On grass managed for silage, which is of an ideal height for nesting skylarks, the frequency of cutting leads to nest loss either directly through destruction by the machinery or indirectly by exposing the nests to predators.

Corn bunting

The corn bunting is another ground-nesting bird almost entirely confined to farmland. A review by Donald (1997) estimated its decline in numbers at 77% between a peak in 1973 and 1992 . He cited as possible causes of the decline the loss of spring tillage, loss of barley, increased use of pesticides, loss of winter food sources, loss of mixed farming, and changes in grassland management. Several of these are probably interconnected. The abandonment of mixed farming in many areas would have resulted in the loss of spring tillage, as spring-sown crops were widely grown for stock feed. These would mostly have been spring barley, hence a connection with barley. The practice of establishing grass leys by undersowing cereals also declined, and with it the area of undersown stubbles that provided food resources throughout the winter in the form of weed seeds and spilt grain (Shrubb, 1997). Better harvesting methods and herbicide use have reduced the food available on remaining winter stubbles. The corn bunting also feeds its chicks on invertebrates, and Aebischer & Ward (1997) found that spring barley held a higher abundance of the preferred prey groups such as caterpillars (Symphyta and Lepidoptera) than winter cereals. They observed that the highest densities of nesting corn buntings coincided with a mixed farming environment, and suggested that, like the grey partridge, productivity in an intensive arable one might suffer from the reduced densities of preferred arthropods in winter cereals, brought about not least by the use of herbicides and insecticides. The corn bunting seems as able to nest in cereals as in grass, so long as the latter is tall enough to conceal the nest. Thus hay fields are preferred to pasture, but increasingly former hay fields are being managed for silage, so are cut too frequently for successful nesting.

Cirl bunting

The cirl bunting was formerly a common resident in southern England, but its numbers collapsed to under 150 pairs by 1989 (Evans, 1992). Evans & Smith (1994) suggested that the reduction in winter stubbles, leading to food shortages, was one factor responsible for the decline. Another may have been a reduction in breeding productivity. As with the previous species, cirl bunting chicks are fed insects by their parents, and late nests are more successful than early ones because of improved chick survival (Evans *et al.*, 1997). It seems that larger more nutritious prey such as Orthoptera (grasshoppers and crickets) are available late in the season, and that early nestlings suffer from a risk of starvation and the attendant risk of predation. Habitats that are rich in such large insect prey have, however, to a large extent disappeared as grassland improvement and higher stocking rates result in lower densities of grasshoppers (van Wingerden *et al.*, 1991), and the reduction in landscape diversity caused by specialisation and the loss of mixed farming also, as already described for other species, results in lower densities of invertebrates.

FOOD RESOURCES AND CROPPING PRACTICES

Several common themes emerge from the species accounts above. One is that for all species, the chick diet is almost entirely composed of invertebrates. There are many ways whereby the intensification of agriculture has resulted in declines in the abundance of invertebrates within farmland. The use of herbicide probably reduced invertebrate densities in cereals by half (Southwood & Cross, 1969). A long-term monitoring study of cereal invertebrates in Sussex has found that since 1970, numbers have approximately halved again (Aebischer, 1991). Although not all taxa have responded in the same way, some chick-food items have followed the overall trend, not least important ones like caterpillars. The period since 1970 corresponds to one of increasing use of foliar fungicides and insecticides on cereal crops. The effect of insecticides upon non-target invertebrates is a major cause for concern. Already twenty years ago, Vickerman & Sunderland (1977) demonstrated the far-reaching effects upon non-target invertebrates of a broad-spectrum insecticide (dimethoate), results that have been confirmed at the field level by, for example, the Boxworth study (Burn, 1989). Latterly, Sotherton (1990) demonstrated the susceptibility of sawfly caterpillars to the summer use of the recently-approved synthetic pyrethroids. Because sawflies reproduce slowly, the impact of a single treatment of a broad-spectrum insecticide can last several years (Aebischer, 1990).

This ties in with another common theme running through the accounts above, namely the loss of mixed farming. In Sussex, Aebischer & Ward (1997) found that the area where densities of sawflies had remained relatively high since 1970 was the area where traditional mixed farming was still practised; the same area held the highest densities of corn buntings and of grey partridges (Aebischer & Potts, 1997). Densities of sawflies on a farm are positively associated with the proportion of fields that are undersown in the previous year (Aebischer, 1990), probably because the insect larvae pupate in the soil before harvest. This means that they are able to overwinter without being destroyed by cultivation, given that after harvest the grass develops into a first-year ley. Moreover, herbicide use on undersown cereals is much reduced because of the presence of a legume within the crop. The understory is therefore weedier and more attractive to invertebrates than a conventional crop. Typically, undersown crops are spring-sown, which benefits ground-nesting birds that prefer to nest in a relatively open situation rather than in dense vegetation, such as skylarks and lapwings.

A third common theme running through the species accounts is that nearly all of the birds are ground-nesting, and are therefore at risk from ground predators. Although the issue of predation is beyond the scope of this paper, it cannot be excluded as a relevant factor.

SYMPATHETIC FARMLAND MANAGEMENT

A number of management options are available based on current understanding of the reasons underlying the declines of farmland bird species, allowing certain beneficial aspects of extensive or mixed farming to be reproduced on intensive farms with little economic penalty.

Selectively sprayed headlands

Conservation Headlands are a tried and tested way of restoring the understory of weeds and their associated invertebrate fauna to the part of the cereal crop most used by foraging birds (Sotherton, 1991). The outer 6-m band of cereals receives only selective herbicide applications, targeted at agricultural pest weeds such as grasses and cleavers (*Galium aparine*). No summer insecticides are allowed. It has been shown experimentally that percentage weed cover and densities of chick-food insects are higher in Conservation Headlands than in conventional crops, and farm-scale trials have demonstrated the beneficial effects upon the survival of grey partridge chicks (Sotherton, 1991).

Grass strips and banks

Beetle Banks are raised strips across fields that are planted with a mixture of tussocky grasses such as cock's-foot (*Dactylis glomerata*) or Yorkshire fog (*Holcus lanatus*) (Thomas *et al.*, 1991). These harbour high densities of predatory beetles over winter, leading to higher densities in the fields during the following spring and summer. The banks also provide shelter and potential nesting cover for partridges, lapwings, skylarks and corn buntings. More generally, grass strips can be planted alongside hedgerows, tracks or roads, or around crops. They should be managed on a rotational basis around the farm, cutting outside the breeding season, so that some cover in the form of tall dead grass is available every year.

Set-aside

Set-aside is the taking of land out of cereal production in return for continued cereal subsidies (Arable Area Payments Scheme), as part of the European Union's Common Agricultural Policy. Current regulations allow considerable flexibility in the management of set-aside for wildlife. Set-aside areas must be at least 20 m wide and cover 0.3 ha. After harvest, they can be left to regenerate naturally, thereby providing stubbles over winter and valuable open nesting or insect-rich foraging habitat during the following breeding season; in this respect it has similar benefits to the establishment of a grass ley through undersowing. If left, the value is likely to decline in subsequent years as the density of the vegetation increases. It can be replaced by sown cover of an unharvestable mixture under the "Wild Bird Cover" option, which can also be implemented without being preceded by natural regeneration. The "Grass Cover" option offers an opportunity to create nesting and foraging habitat in close proximity to arable crops, and can be an alternative to Beetle Banks. Up to 2 m next to a hedge or wood may be left uncut each year, so rotational cutting every 2-3 years will prevent scrub formation while maintaining nesting cover.

Pesticides

Broad-spectrum herbicides should not be used on hedge bottoms, banks or grass strips, and drift from adjacent crops should be prevented, to avoid creating suitable conditions for the establishment of agricultural pest weeds such as barren brome (*Bromus sterilis*) and cleavers. These weeds can be treated with selective products with little harm to other vegetation (Boatman, 1992), as in Conservation Headlands. Insecticides should be applied in strict accordance with known threshold numbers of insect pests, avoiding drift from the crop into adjacent margins, and if possible leaving the outer 12 m of crop unsprayed. Where aphid control is necessary in the summer, compounds containing pirimicarb should be used (Anon., 1997). The establishment of a buffer strip between field margin and crop protects the margin from pesticide drift, and protects the crop from weed encroachment (Anon., 1997).

DISCUSSION

In combination, the cropping and management practices described above address many of the negative consequences of the intensification of agriculture that have been shown or are thought to be agents in the declines of farmland birds. Many of them involve manipulations of land that could be used for growing crops, so there is an element of profit foregone if they are implemented. From this point of view, set-aside is particularly valuable not just for its flexibility, but because it is a mandatory requirement for the receipt of Arable Area Payments, so that the land is already out of production. Nevertheless, the cost of many of the other practices can now be recovered partly or fully under a range of government schemes. In certain Environmentally Sensitive Areas in England (Brecklands, Clun, South Downs, South Wessex Downs) and Scotland (Central Borders, Stewartry), farmers may receive payments for Conservation Headlands under agreement with MAFF or DAFS. In Wales, payments for Conservation Headlands are available as part of the Tir Cymen package of countryside measures, while in Scotland, unsprayed headlands are funded within the Countryside Premium Scheme. Under the Countryside Stewardship Scheme (England), Tir Cymen (Wales) and Countryside Premium Scheme (Scotland), grants can be made available for Beetle Banks, grass strips, hedgerow planting and traditional hedgerow management. More generally, several Environmentally Sensitive Areas offer payments for the extensive management of grassland, and in the case of the South Downs ESA since 1997, for elements of mixed farming such as overwinter stubbles and undersown spring crops.

Because of its ubiquitous, extensive and flexible nature, set-aside constitutes the backbone of these measures. A potential problem therefore is the uncertainty about the long-term future of set-aside, whose sole justification is arable overproduction. What is needed is an integrated package of funded measures designed specifically to improve the arable environment for wildlife. The British government has just approved a pilot run, starting in 1998, of the Arable Stewardship Scheme proposed jointly by The Game Conservancy Trust, the Royal Society for the Protection of Birds and English Nature. This scheme will be implemented under EU Agri-Environment Regulation 2078/92. It seeks to promote mixed farming by supporting spring cropping and undersowing, provide an equivalent of the wildlife-friendly options of set-aside in the form of overwinter stubbles and cover crop mixtures, and bring related measures like Conservation Headlands, Beetle Banks and grass margins together under one umbrella. What remains is to co-ordinate the prescriptions and payments under the Arable Stewardship Scheme and the Environmentally Sensitive Areas to produce an effective conservation support infrastructure for declining farmland birds and other wildlife nationally.

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THE DIET OF NESTLING LINNETS *CARDUELIS CANNABINA* BEFORE AND AFTER AGRICULTURAL INTENSIFICATION

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ABSTRACT

During the 1996 breeding season, the diet of nestling linnets was examined on mixed lowland farmland near Oxford, U.K. Here we present the results of this study and compare them with those of a similar study carried out in the same area in 1962-1964 by Newton (1967). Results show that whilst the number of food taxa fed to nestling linnets has changed little, diet composition is markedly different. Some dietary items have become much more prominent than in the 1960s (e.g. seeds of dandelions (*Taraxacum* spp.) for early broods), whilst other previously preferred seeds are now rare due to chemical weed control (e.g. charlock *Sinapis arvensis*). Charlock seed has now been replaced in the diet by that of cultivated oilseed rape (*Brassica napus oleifera),* to the extent that many broods are fed almost exclusively on this food source from June onwards. Despite agricultural intensification over the last 30 years, overall seed availability is unlikely to be an important factor limiting linnet populations in mixed farming systems where oilseed rape and grassland sources of seeds of *Taraxacum* spp., chickweed (*Stellaria media)*, docks (*Rumex* spp.) and thistles (*Cirsium* spp.) are available. In intensively managed, pure tillage systems, breeding season food availability may be severely limited if oilseed rape is not part of the crop rotation.

INTRODUCTION

In recent decades, many farmland bird species have undergone marked population declines in Britain and much of Europe (Tucker & Heath, 1994). Changes in agricultural practices have often been cited as contributing to these declines, particularly via the reduction in availability of both invertebrate and seed food resources (e.g. Campbell *et al.*, 1997). Previous studies of chick diet of farmland birds have concentrated on invertebrate foods. For example, work on the grey partridge (*Perdix perdix*) has shown that insecticide and herbicide use on cereal crops has removed much of the invertebrate food in field margins upon which chicks depend for the first few weeks of life (Potts, 1986). This reduction in food availability is caused either directly, by the toxicity of insecticides, or indirectly by the removal of host food plants upon which the invertebrates depend (Campbell *et al.*, 1997). The young of most other farmland bird species of conservation concern have a similar invertebrate diet, but the linnet (*Carduelis cannabina*) and other species of its genus (e.g. goldfinch *C. carduelis* and greenfinch *C.*

chloris) are unusual in relying almost exclusively on a diet of partially ripe seed, even when feeding chicks (Newton, 1967). Linnets are only loosely territorial and semi-colonial when breeding, and adults may fly up to 2km from the nest to collect seed food which is stored in the gullet and regurgitated to nestlings (Cramp & Perrins, 1994). This gives linnets considerable independence of food availability immediately around the nest. The linnet is currently a species of high conservation concern, having declined on farmland in Britain by 41% between 1968 and 1995 (Siriwardena *et al.*, in press). This reflects a decline of over 50% up to 1987, followed by some recovery since then.

This study compared the nestling diet of linnets in 1996 with that recorded in 1962-1964 by Newton (1967), before the species' population decline and before the onset of pronounced agricultural intensification in England. Both studies were carried out on lowland mixed farmland and adjacent habitats in Oxfordshire (all Newton's sites), Warwickshire and Wiltshire, and some of the data in the two studies were collected from exactly the same site, the Oxford University estate at Wytham. The study aimed to measure how linnet nestling diet differed before and after a period of pervasive agricultural intensification and prolonged population decline, and assess whether the change suggests that reductions in seed availability may have been a factor in the species' population decline in lowland farmland habitats.

MATERIALS AND METHODS

Linnet nests were found in hedgerow habitats on three organically managed and four conventional mixed farms between April and August 1996. Linnet nestlings, like those of other cardueline finches, store food in their gullet prior to digestion. The gullet is covered by transparent skin. By harmless manipulation of the gullet contents between thumb and fore-finger it is possible to identify individual food items and record the percentage of total seed volume occupied by each seed type. In total, 187 broods (699 chicks) were visited on 1-3 (usually two) occasions to record these data for comparison with those published by Newton (1967). Newton recorded data from only 62 broods, but each was visited much more frequently (some over 100 times) during May to August 1962-64. Ideally, to avoid pseudoreplication, data from repeat visits to a brood would be pooled before analysis. However, the results published by Newton (1967) do not permit this so, for ease of comparison, we have also treated each brood-visit independently in the 1996 data set, whilst recognising that the degree of repeat visiting varies greatly between the two studies, and that sophisticated statistical comparison of the data sets would be inappropriate.

RESULTS

Table 1 shows the mean percentage of total gullet seed volume occupied by each seed type for May - August, comparing the 1962-64, and 1996 data sets. The total number of gullets examined provides a measure of sample size, bearing in mind that the 1962-64 data set represents intensive repeat sampling of 62 broods, whilst the 1996 data set represents limited repeat sampling of 187 broods.

Table 1. Seasonal variation in diet composition of linnet nestlings in 1962-1964 (from Newton, 1967) and 1996 (this study). Data are presented as mean percentage of gullet volume for each seed type.

(a) May	**1962 - 1964**	**1996 (Organic)**	**1996 (Conventional)**
Number of gullet observations	*567*	*45*	*22*
Taraxacum spp.	42	97.5	84.5
Stellaria media	40	+	1
Ulmus spp.	9		
Grasses (mainly *Poa* spp.)	8	+	+
Senecio vulgaris			14

(b) June	**1962 - 1964**	**1996 (Organic)**	**1996 (Conventional)**
Number of gullet observations	*1836*	*156*	*126*
Stellaria media	26	5	5
Ulmus spp.	20		
Taraxacum spp.	19	60.5	40.5
Alliaria petiolata	10	1.5	4.5
Rumex spp.**	8		
Ranunculus spp.	6		
Hypochaeris spp.	4		
Capsella bursa-pastoris	3		+
Senecio vulgaris	1	+	2
Oilseed rape		29.5	42
Cirsium spp.		2	
Sonchus spp.			1.5
Grasses (mainly *Poa* spp.)			1.5

(c) July	**1962 - 1964**	**1996 (Organic)**	**1996 (Conventional)**
Number of gullet observations	*1054*	*130*	*113*
Sinapis arvensis *	28		
Hypochaeris spp.	21		
Rumex spp.**	17	1.5	+
Ranunculus spp.	10		
Polygonum spp.	4.5	+	14
Ulmus spp.	4		
Alliaria petiolata	3		4.5
Capsella bursa-pastoris	3	4.5	1.5
Stellaria media	2	+	+
Sonchus spp.	2	11.5	3
Senecio vulgaris	2	+	
Taraxacum spp.	1	+	5
Cirsium spp.	+	+	2.5
Grasses (mainly *Poa* spp.)	+		1.5
Oilseed rape		75	66

(d) August	1962 - 1964	1996 (Organic)	1996 (Conventional)
Number of gullet observations	*522*	*59*	*48*
Cirsium spp.	42	5.5	16
Sinapis arvensis *	39		
Polygonum spp.	6		5.5
Ranunculus spp.	3		
Chenopodium spp.	3		
Hypochaeris spp.	1		
Sonchus spp.	1	4	2.5
Capsella bursa-pastoris	+	4	+
Oilseed rape		71.5	50.5
Alliaria petiolata			2

* other wild Cruciferae may have been taken, but *S. arvensis* was the main species present.

** in 1962-1964, this refers to *R. acetosa*; in 1996 to *R. obtusifolius/crispus*.

Other foods never comprising >1% of gullet volume in any month in either study are: linseed *(Linum usitatissimum*), speedwells (*Veronica* spp.), field pansy (*Viola arvensis*), mayweeds (*Matricaria* spp.), leaves of hawthorn (*Crataegus monogyna*), aphids and caterpillars.

In 1996, a few species were especially dominant in nestling diet, notably dandelion (*Taraxacum* spp.) and oilseed rape (*Brassica napus oleifera*), and diet composition differed little between organically and conventionally farmed study areas. Oilseed rape was absent from the diet in 1962-64 as it was then virtually unknown as a crop and would not have occurred in Newton' study areas, but dominated the nestling diet of linnets in 1996, from June to the end of the breeding season. Of dietary items taken in 1962-64, only *Taraxacum* spp. and sow-thistles (*Sonchus* spp.) are now clearly more important components of the diet, whilst charlock (*Sinapis arvensis*), catsears (*Hypochaeris* spp). and elms (*Ulmus* spp.) were completely absent in 1996, and chickweed (*Stellaria media)*, garlic mustard (*Alliaria petiolata*), thistles (*Cirsium* spp.), and buttercups (*Ranunculus* spp.) were all much less frequently taken. Sorrel *(Rumex acetosa*) was an important dietary component in June and July in 1962-64, but was absent in 1996, being replaced by much smaller numbers of seeds of broad-leaved dock (*R. obtusifolius*) and curled dock (*R. crispus*). There are marked seasonal changes in nestling diet. In 1996, *Taraxacum* seeds were taken almost to the exclusion of other foods in May, and were then gradually replaced by oilseed rape through June and July. By August, oilseed rape was still a prominent food item, though the contribution of other seeds (e.g. *Cirsium* spp.) increased to its peak at this time. In 1962-64, early linnet broods were fed on a more even mixture of *Taraxacum* spp. and *S. media*, with *Ulmus* spp. and *A. petiolata* also important. In later broods, nestlings were fed on a wide variety of seeds, with those of *S. arvensis* , *Hypochaeris* spp., *Ranunculus* spp., *R. acetosa* and *Cirsium* spp. as dominant components.

DISCUSSION

Changes in diet composition through the breeding season suggest that seeds of certain species (especially *Taraxacum* spp., *S. arvensis*, *Cirsium* spp., and oilseed rape) are taken preferentially as soon as they are available. The two plants which now dominate the diet of nestling linnets in Oxfordshire, *Taraxacum* spp. and oilseed rape, are both extremely common. The former are very persistent weeds growing commonly in pasture, meadows, field margins and waste ground, and setting seed throughout the breeding season, though predominantly between April and June. They disperse well, favour fertilised soils, are highly resistant to grazing and trampling, regenerate from root fragments after cultivation and germinate at a wide range of temperatures (Grime *et al.* 1988; Cousens & Mortimer 1995), making them highly persistent in agricultural habitats. Although there is some evidence that *Taraxacum* spp. have declined in intensive arable systems (Andreasen *et al.* 1996), they are probably still increasing, overall (Grime *et al.* 1988). Oilseed rape, almost completely absent in the 1960s, has become a valuable cash crop covering around 0.3-0.4 million hectares per year (Anon., 1995). As the crop has been selected to produce seeds with higher levels of energy- rich oil and lower levels of unpalatable or toxic erucic acid and glucosinolates (e.g. Kirk 1992), rape seed may be improving in quality as a nestling food. In any case, oilseed rape is now by far the most easily available brassica seed, as *S. arvensis* has become rare on all study areas as a result of effective herbicide control since the 1960s (e.g. Chancellor 1985). Moreover, whereas seeds of *S. arvensis* only became available in July, autumn-sowing of oilseed rape means that seeds are available from early June through to the end of the breeding season in August. Though still taken, the seeds of *S. media* are now a much less dominant component of linnet nestling diet than in the 1960s. Although *S. media* is well controlled by herbicides and has declined on some arable farmland, it benefits from high levels of nitrogen input and has often increased in grass swards (Cousens & Mortimer 1995; Andreasen *et al.* 1996). On mixed farmland it seems unlikely that *S. media* has declined in availability, so its reduced contribution to linnet nestling diet may simply reflect greater abundance of preferred *Taraxacum* spp. and oilseed rape in the 1996 study. Of other important food items, the disappearance of *Ulmus* spp. seeds from the diet probably reflects the impact of elm disease on wych elm (*Ulmus glabra*), whilst *R. acetosa* and *Ranunculus* spp. decline rapidly when grassland is improved, and are probably rarer now than in the 1960s (Grime *et al.* 1988). All *Rumex* seed seen being taken by linnets in 1996 was from broad-leaved dock (*R. obtusifolius*) and curled dock (*R. crispus*) which remain common weeds of unimproved grasslands (Grime *et al.* 1988). The absence of *Hypochaeris* spp. from the 1996 data set is more difficult to explain, but it was certainly not commonly available on the study areas in 1996.

The similarity in diet composition of nestling linnets on the organic and conventional study areas in 1996 partially reflects the distances linnets will fly to favoured food sources, thus making seeding *Taraxacum* spp. and oilseed rape fields easily available to most breeding pairs. If these seed sources are consistently preferred when available, then differences between the organic and conventional farms (e.g. Brooks *et al.* 1995) may not influence the birds' foraging behaviour. For example, small patches of *S. arvensis* were available to linnets in cereal fields on some organic fields in the 1996 study, but were never seen to be exploited.

The composition of linnet nestling diet, and abundance of its preferred food plants on mixed farmland in Oxfordshire suggest that overall seed availability is unlikely to be an important factor limiting the productivity of breeding linnet populations in a mixed farming area where oilseed rape is sown. However, field margins, leys and pastures are likely to be important as a source of seeds of *Taraxacum* spp., *S. media*, *Cirsium* spp. and *Rumex* spp. (docks), plus *Ranunculus* spp. and *Rumex acetosa* where the grassland is unimproved. Pure arable landscapes where most of the linnet's important food plants are efficiently controlled by herbicides may support much lower breeding linnet densities, especially in areas where oilseed rape is not commonly sown.

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SESSION 9B

GLOBAL DEVELOPMENTS IN HERBICIDE TOLERANT CROPS

Chairman	DR J B SWEET *National Institute of Agricultural Botany, Cambridge, UK*
Session Organiser	DR G MARSHALL *Scottish Agricultural College, Auchincruive, UK*
Papers	9B-1 to 9B-4

COMMERCIAL EXPERIENCE AND BENEFITS FROM GLYPHOSATE TOLERANT CROPS

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ABSTRACT

Following the introduction of Roundup Ready (glyphosate) tolerant soybean and canola in 1996, commercial experience has demonstrated that growers have achieved outstanding control of annual and perennial weed species. Furthermore, increased flexibility of application timing, in addition to the simpler agronomic management which comes from using a post-emergence glyphosate weed control programme, have provided additional economic benefits. Excellent crop selectivity was observed in both soybean and canola, and when field comparisons were made against other herbicide treatments, higher yields have been recorded. Similar yield advantages have been observed in development trials with Roundup tolerant sugar beet. In soybeans, significant reductions in herbicide use were recorded when a glyphosate programme was used instead of alternative selective herbicide products, demonstrating that glyphosate tolerance is one trait which can make a significant contribution to sustainable agricultural systems.

INTRODUCTION

Prior to analysing the benefits arising from any of the major new biotechnology products, it is interesting to analyse society's expectations for such technology to continue to improve the efficiency of food production. Over the past 25 years, the focus of consumer spending has changed dramatically, with ever decreasing amounts of the household budget being spent on food. In 1970, the mean percentage of disposable income consumers spent on food across OECD countries was 23-25 percent, while today's mean is 15-16 percent (Eurostat 1970-1994). Growing personal incomes and increased efficiency of food production are two main factors in this trend. Since 1970, consumers have been offered higher quality foods at lower prices, and they have come to expect similar offers of value for money in the future.

Dramatic improvements in the efficiency of crop production have developed in the same 25 years. For example, maize yields in Italy have more than doubled from an average of 4.6 t/ha in 1970, to an average of 9.3 t/ha in 1996 (Eurostat 1970-1996), comprising an average yearly increase of 3 %. Plant breeding, fertilizer, farm machinery, crop protection chemicals, and most recently, information technology, are all responsible for this increased efficiency. A historical analysis of farm incomes indicates that over the last 20 years, real agricultural incomes followed a slight and rather unsteady upward trend at an average rate of about 1% per year, partly as a result of these new technologies (European Economy 1994). However, during the 1980's, the average GNP per agricultural worker increased by around 2% per year, so that agricultural workers' incomes have fallen in relative terms. Therefore, although growers have been the primary beneficiaries of numerous agronomic advances, the most notable economic benefits of new technologies are in fact passed to the end consumer via the food processing and distribution industry. It is therefore extremely important for the agricultural supply industry to continue to deliver product benefits which can cascade down through the supply chain to the benefit of the end consumer, if higher-quality food products are to be offered at competitive prices, as the trend has been in the last 25 years.

In terms of food quantity, more food has been required, and it will continue to be required, by the growing world population. The world population numbered approximately 2 billion in 1930. It was 30 years before it reached 3 billion in 1960. However, from 1960 to 1996, the world population growth rate accelerated dramatically, doubling from 3 billion to 6 billion in only 36 years (Dyson 1996). The United Nations predicts that the acceleration in growth will continue, and forecasts a population increase of 49 % between 1990 and 2020. By far the greatest increases are predicted in Africa and the Middle East. Population growth is not the only factor to determine food quantities necessary in the future. Lifestyle is another consideration where the tastes and disposable incomes of developing societies are moving up the food value chain from a focus on grains to meats and fresh produce.

Of course, food quality and quantity depend on distribution networks. Incursions into the environment due to population growth, housing development and infrastructure expansion have already left their scars on the world landscape. Where more ancient populations demanded the conversion of forest and meadow into farmland and pasture, today's populations demand a further remove from the natural state by re-converting farmland into construction sites for urban development. In Western Europe, over 2 million hectares of agricultural area have been lost to urbanization and other non-agricultural uses over the past 20 years (Eurostat). In the United States, the loss of agricultural area has been even more spectacular, where 3.7% of agricultural land has been lost to urbanisation between the early 1970's and the early 1980's (USDA 1990).

From the decreasing dedication of land to agriculture, it is reasonable to expect that current food surpluses in the Western world will be succeeded by potential food shortages early in the next century, as populations grow with shrinking agricultural bases of support. There are two stark resolutions to this problem: to more than double the area of cultivated land, or to more than double the yields from land already under cultivation. Expanding cultivated area to the necessary degree would require an increase in area from 15 million to 40 million square kilometers (Avery 1994). Such an increase would have devastating environmental consequences in terms of habitat destruction and human displacement. The second option, to increase production on land that is already cultivated, is therefore a far more acceptable solution in social and environmental terms.

Within this macro-economic landscape, modern plant biotechnology will have a critical role to play in feeding the world by improving efficiency and fostering more sustainable agricultural systems. Weed control is a critical element in optimising crop yield and there are many reasons why new weed control systems are needed. First of all, better weed control systems coupled with greater timing and application flexibility will lead to improved crop production systems. Historically, as each new class of herbicide is introduced, crop phytotoxicity is reduced, but loss of production from herbicide injury remains a significant yield reducing parameter. Finally, new weed control systems incorporating herbicides with favourable human safety and benign environmental characteristics are required to reduce environmental impact and to drive more sustainable agricultural systems into practice.

In the mid-1980's, glyphosate was identified as a product which, if used on crops genetically modified to tolerate post-emergence applications, would meet the above criteria for yield maximisation, a high degree of human safety and minimal environmental impact (Kishore *et al.* 1988). Glyphosate exhibits a high level of control with almost all annual and perennial grass and broadleaf weeds, and is effective through a wide range of growth stages on emerged weeds. The positive safety and environmental features of glyphosate include rapid soil biodegradation as well as extremely low toxicity to mammals, birds and fish (Malik *et al.* 1989). Therefore, glyphosate is an attractive candidate for inclusion in sustainable agricultural systems.

The introduction of crops containing Roundup Ready™ genes (Monsanto's trademark for genes conferring tolerance to Roundup® herbicide) presents growers around the world with the opportunity to improve weed control management in an environmentally sound way, while giving the same growers a yield advantage which can help meet future needs for increased production from finite or shrinking areas of farmland.

ROUNDUP READY CROPS

The first Roundup Ready crops were introduced in 1996. Soybeans were commercialised in the United States and Argentina, and canola (spring oilseed rape) was commercialised in Canada. The second wave of crops includes Roundup Ready cotton, which is being marketed for the first time in 1997 in the United States.

In Europe, it is foreseen that Roundup Ready crops will be introduced from 1999, the major crops being sugar beet, maize, oilseed rape, soybean and cotton. In assessing the performance and benefits of glyphosate tolerant crops, the results from the 1996 commercial introductions serve as an excellent source for review.

SOYBEAN

In 1996, seed companies in the United States had sufficient seed stocks to plant approximately 400,000 hectares of Roundup Ready soybeans, or about 1.5% of the national crop. In Argentina, the area grown was principally dedicated to seed production. To monitor product performance, and to quantify the benefits of this new technology, more than 1,000 growers in the United States were randomly selected to take part in a post-use market research survey. The overall data presented in this paper were weighted to reflect the actual distribution of users in each soybean growing region.

Overall, 74 % of the users indicated they had made only one application of Roundup post-emergence of the soybeans. This single application was made at an average rate of 2.1 litres per hectare, and it was generally the norm in the Midwest and Southeast United States. By contrast, Delta growers in the South averaged two post-emergent applications, the second applied at an average rate of 1.75 litres per hectare.

The Roundup applications were timed according to weed stage, and the first applications of Roundup were made about four weeks after planting when the weeds were 10-20cm in height. Typically, the crop had reached the 3-4 trifoliate leaf stage at time of spraying. If a second application was needed, it was generally applied about six and a half weeks after planting, at the 6-7 trifoliate leaf stage. The difference in weed pressures that accounted for the variation in numbers of sprays was largely geographical: the southern weed population was more diverse, and a higher number of weeds germinated over longer periods of time due to the longer growing season which encourages a second flush of weeds. Often multiple species are present in the Delta, rather than a predominance of *Setaria* as is frequently observed in the mid-west. It is not unusual to see a complex of monocots grasses in the south, such as *Echinochloa*, *Digitaria*, *Brachyaria* and *Eleusine*.

Use of residual herbicides was limited, as only 18% of growers used any residual herbicide with their Roundup Ready crop. However, residual herbicides were somewhat more common in the Southern Delta region, reflecting the heavier weed pressure in this warmer, more humid region. The most commonly used residual products were trifluralin and pendimethalin.

When growers were asked to comment on the performance of the product, 90 % of growers stated that their expectations had been met or exceeded with Roundup Ready (Table 1).

Table 1 Summary of product expectation responses

Rating	% Growers
Very much exceeded expectations	27 %
Exceeded expectations	22 %
Met expectations	41 %
Failed to meet expectations	7 %
Very much failed to meet expectations	2 %
Don't know	1 %

Growers observed that Roundup Ready soybeans "yielded well". This observation was substantiated by data from 75 field locations where Roundup Ready soybeans were treated with a traditional herbicide programme and compared side-by-side with Roundup treatment. The average yield benefit from the Roundup treatment was 4.8%. There could be a number of reasons for this yield response. The most likely answers are iterated by growers in their list of benefits: first, Roundup gives a very high level of weed control; second, the improved crop exhibits a very high level of safety from the treatment.

Benefits to the grower are best captured by the survey question *"In what way did the product exceed expectations ?"* (Table 2).

Table 2 Reasons Roundup Ready exceeded expectations

Rating	% Growers
Yield Well	43 %
Clean Fields	48 %
No Crop Injury	11 %
Cheaper/Cost Effective	9 %
Met Expectations	6 %
Single Pass	5 %
Easy Program	4%
Good Control of Johnsongrass	4 %
Can Spray over-the-top	4 %

n = number of respondents (total = 486)

The positive impact left by the product is reflected in the re-purchase intent of users: 88 % of 1996 users planned to plant Roundup Ready soybeans in 1997. Actual plantings of soybeans in 1997 are estimated at 4 million hectares, representing 15% of the total 27 million hectare United States soybean crop. The only constraint on the 4 million hectare planted area was seed availability. The 1997 Roundup Ready soybean crop includes more than 100 varieties produced by more than 80 seed companies.

A similar market research survey of Roundup Ready soybean growers was conducted in Argentina following the introduction of 75,000 hectares of the crop in 1996. Results were equally positive from farmers surveyed in South America, who listed the primary benefit of the technology as better control of weeds: both perennial and annual grasses, broadleaf weeds and larger weeds. Cost saving and ease of application were the other benefits cited by Argentine users.

In order to quantify some of the environmental benefits offered by Roundup Ready technology, a study was also conducted in the United States to estimate the impact of this new product on herbicide usage (Table 3, Sparks 1997 pers. comm). Whilst the sheer amount of herbicide used is an incomplete measure of environmental impact, it is a parameter upon which experts as well as members of the public may begin to evaluate the merits of a new technology. Herbicide use was on average lower in Roundup Ready soybean fields than in those treated with competitive products, partly because growers were able to achieve superior weed control without pre-emergence herbicide treatments. Reductions in herbicide use ranged from a high of 39% in the Southeast, to a low of 9% in the East Central region of the United States.

Table 3 Herbicide use patterns in the USA (1996)

Region	Herbicide use reduction measured as active ingredient (kg/ha)		
	Standard	Roundup Ready	% Reductions
Southeast	1.45	0.88	39 %
Mid-South	1.46	1.00	31 %
West-Central	1.06	0.89	16 %
East-Central	1.04	0.96	9 %

Variations in herbicide reduction rates are attributable to variable soil and climatic conditions which affect weed pressure and variations between weed populations in different geographic regions. Reductions also vary due to farmers' use of the technology: while some farmers planted Roundup Ready soybeans on their most difficult fields, others took a more conservative approach, and planted them where weed pressures were average.

CANADIAN EXPERIENCE WITH ROUNDUP READY CANOLA

In Canada, seed availability limited introductory sales of Roundup Ready canola to approximately 20,000 hectares in 1996. Although the user base was significantly smaller than was the case with soybeans, 289 individual grower surveys were conducted to establish user perception of this new product. The majority of the users (220) were located in Saskatchewan and the remainder in Manitoba and Alberta.

Almost all growers used the recommended application rate of 1.2 litres per hectare, and most applied Roundup at the 3-4 leaf stage of the crop. Eighty percent of the growers surveyed used only one in-crop application of Roundup; the remaining 20% made a second application. A summary of weed control impressions is provided in Table 4:

Table 4 Weed control in Roundup Ready canola (1996)

Overall weed control 21 days after treatment (% of growers responses)

Rating	Annual n = 1257	Perennial n = 499
Excellent	81%	52%
Good	14	36
Fair	5	10
Poor	1	2

n = number of weed records

The most prevalent annual weeds were *Avena fatua*, *Sinapis arvensis*, *Gallium aparine*, *Thlaspi arvense*, with perennial infestations of *Cirsium arvense* and *Agropyron repens* amongst others. Farmers surveyed reported excellent weed control under a wide range of weed stages and growing conditions.

Crop safety

Farmers were asked to comment on perceived crop safety of Roundup Ready compared with other herbicides. Over forty percent of users rated crop safety above other canola herbicides used on the farm. Crop safety impressions are summarised in Table 5:

Table 5 Summary of crop safety in Roundup Ready canola (1996)

Perceived Crop	Number of Roundup Applications	
Safety	One	Two
Better	43	46
Same	56	52
Worse	1	2

Crop yield

In 1996, thirty-one growers performed side by side strip trials with other products including imazethapyr and glufosinate tolerant varieties. Each field had the same crop rotation history and similar weed spectra. The average yield advantage from Roundup Ready was 163 kg/ha, representing a yield benefit of 9.3 %. As with Roundup Ready soybeans, the yield response is due to the high level of weed control, coupled with improved crop safety.

SUGAR BEET

Roundup Ready oilseed rape, maize, cotton, soybean and sugar beet are in development for the European market, and introductions of these crops are planned to commence in the 1999-2000 time frame._Some of the results of development work on Roundup Ready sugar beet serve to illustrate the benefits which Roundup Ready technology can offer to European farmers. As a crop, sugar beet are particularly sensitive to both weed competition and phytotoxicity from herbicides used to control competing weeds. Canopy closure in sugar beet does not occur until three months after sowing, and the impact of weed competition on yield is well documented, as is the potential damage from herbicides when applied under less than optimum conditions.

The Roundup Ready sugar beet varieties currently under development convey a high degree of tolerance to Roundup at all growth stages, whereby avoiding the yield-diminishing phytotoxic effects of some current herbicides. In independent trials and Monsanto trials, control of annual and perennial weeds using two to three applications of Roundup has produced excellent weed control results. (Table 6)

In such application programmes, Roundup application has totaled 4 to 6 litres per hectare and control of all major sugar beet weed species has been achieved without the need for additional residual or contact herbicide treatments. A programme of sequential applications controls weeds at the optimum early stages of development, from cotyledon to the four leaf stage. As with Roundup Ready soybean, timing of Roundup application to sugar beet is determined by weed stage. Crop stage is immaterial to application schemes, as the sugar beet crop shows a very high level of safety to Roundup herbicide, from the cotyledon stage through to canopy closure.

Table 6: Weed control Assessment in Roundup Ready Sugar Beet Trials.

Summary of 32 trials (France, UK, Belgium, Denmark, Italy, Spain - 1995 -1996)
% Control of major weeds -August assessment

	Application Rate		
	2 x 2 l/ha	3 x 2 l/ha	2 x 3l/ha
Aethusa cynapium	99	100	100
Alopecurus myosuroides	100	100	100
Amaranthus retoflexus	100	100	100
Capsella bursa pastoris	100	100	100
Chenopodium album	98	100	100
Echinochloa crus-galli	90	95	100
Elymus repens	90	98	100
Fumaria officinalis	100	100	100
Galium aparine	95	98	100
Lamium purpureum	95	100	100
Matricaria chamomilla	98	100	100
Mercurialis annua	90	96	95
Polygonum aviculare	97	100	100
Polygonum convolvulus	85	100	100
Polygonum persicaria	97	100	100
Raphanus raphanistrum	99	100	100
Sinapis arvensis	100	100	100
Solanum nigrum	97	99	99
Stellaria media	100	100	100
Urtica urens	90	95	98
Veronica spp	100	100	100
Viola spp	99	100	100
Weed Beet	100	100	100

Control of late germinating weeds such as *Chenopodium album* has been achieved at canopy closure, even when much of the surface area of the weed has been shielded by beet foliage.

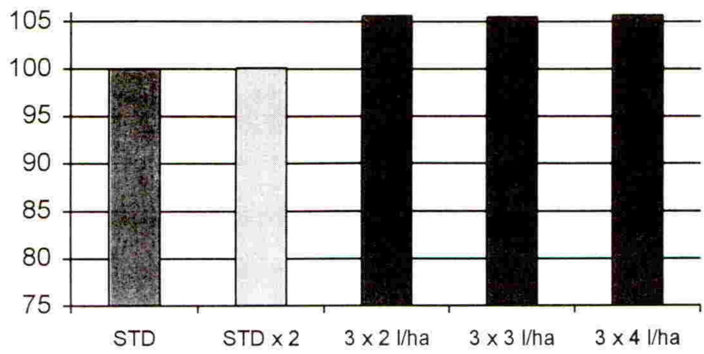
Control of such weeds at advanced stages is made possible by the systemic action of glyphosate herbicide. It has been observed that sequential applications of Roundup have been more effective than a single application made at the same total rate because the programmed approach gives an additive herbicidal effect. The use of Roundup on Roundup Ready varieties gives growers a significant benefit by controlling weed beet. Weed beet limit the potential of crop rotation programmes in many European regions in which sugar beet are grown intensively. To maximise the longevity of this benefit, it is recognised that an appropriate management programme will need to be instated to prevent the possible build up of glyphosate tolerant bolters. In trials, control of volunteer potatoes has also been a major advantage of the selective application of Roundup in sugar beet. Application timing, flexibility, high crop selectivity, and broad-spectrum weed control given by Roundup Ready varieties will offer a unique weed control tool for the sugar beet grower.

Crop Yield

As with the other Roundup Ready crops previously discussed, the combination of effective weed control and excellent crop safety offered by Roundup Ready sugar beet has led to increased yield responses being observed in many trials. An average yield response increase of 3% to 5% has been observed in 35 trials over 3 years. Although it is too early to speculate if yield responses observed in trials will extend to commercial experience, the intent is to combine the Roundup Ready trait with competitive high-yielding elite germplasm in order to gain consistent yield benefits at commercial level.

Results from trials conducted in 1996 at 12 locations in France, UK, Denmark, and Belgium are summarised in Figure 1. The average yield advantage from Roundup application was 5% when compared to other herbicide programmes, where the standard treatment represented good husbandry practice for the sugar beet region and typically included a pre-emergence application followed by two to four post-emergence treatments. This yield advantage was also observed at a dose rate of 12 litres per hectare, double the maximum recommendation of 6 litres per hectare. These differences were significant at P=0.05. Similar yield advantages were also observed in yield of refined sugar.

Figure 1: Root fresh weights from the 1996 sugar beet selectivity trials
Standard treatment referenced at 100.



DISCUSSION

Commercial and trial experience with several Roundup Ready crops demonstrates that glyphosate tolerance conferred by genetic modification opens up new opportunities for increased crop production whilst enhancing the environmental profile of agronomic inputs. In market research conducted amongst the 'early users' of Roundup Ready technology, a frequently cited benefit is that glyphosate tolerance makes weed control management easier and more effective. The technology therefore reduces husbandry management 'risk' - a significant component of modern farm management. The broad weed control attributes, excellent crop safety and wide application window of glyphosate gave users the security of effective and simplified crop management. The yield benefit typical of the Roundup Ready trait may appear to be only an additional benefit to improved weed control for growers. However, that same benefit makes significant strides towards maintaining the value for money that consumers expect to find on offer in their local food stores, while at the same time it makes progress towards an agricultural system which could overcome the limited area of currently cultivated land.

The Roundup Ready trait is one of the first of many new traits generated using genetic modification techniques. The first experiences of farmers are extremely encouraging and go some way to illustrate that increased food production can be made safer and more efficient through the use of modern biotechnology. The same technology can eventually improve the nutritional quality of foods as well as the harvested quantity, while at the same time it reduces the impact of modern farming practices on the environment by reducing dependence on chemical pesticides.

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GLUFOSINATE AMMONIUM TOLERANT CROPS - INTERNATIONAL COMMERCIAL DEVELOPMENTS AND EXPERIENCES

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ABSTRACT

Oilseed rape (canola), maize, soybeans, sugar beets and other crops have been genetically modified to become tolerant to the non selective herbicide glufosinate ammonium. Since 1990 numerous field trials have been conducted for development and approval of tolerant varieties and registration of the herbicide. In spring 1995 Canadian authorities were the first to approve all commercial uses of the first two glufosinate ammonium tolerant canola varieties. At the same time they granted the registation of glufosinate ammonium with the brand name Liberty™ for selective weed control. The new weed control technology was launched as the Liberty Link™ system. In 1997 about 830 000 ha of Liberty Link canola was grown. Canadian farmers have now fully accepted this profitable canola production system. In the USA Liberty herbicide and Liberty Link maize hybrids were launched also successfully on large scale this year. In 1998 the Liberty Link system is expected to be launched in Europe.

INTRODUCTION

Glufosinate ammonium is a widely used non-selective herbicide controlling an exeptional broad spectrum of broadleaf and grass weeds. It is one of the most attractive modern herbicides and has favourable properties regarding safety of humans, animals and the environment. Therefore there has been a great desire and a lot of efforts to use glufosinate ammonium also for selective weed control in major field crops.

The dream has become a reality. Crop tolerance to glufosinate ammonium has been achieved for the first time by genetic modification of plants about 10 years ago. De Block *et al.*, (1987) inserted a resistance gene, the BAR gene, into plants which were then protected against the herbicidal effects of glufosinate ammonium. Independently Strauch *et al.*, (1988) isolated another resistance gene, named the PAT gene, which was inserted into a range of dicot crops (Donn *et al*, 1990a) and maize (Morocz *et al.*,1990, Donn *et al.*, 1990b). Both resistance genes show nucleotide sequence homology and code for an enzyme which inactivates glufosinate ammonium by a highly specific acetylation to N-Acetyl-L-glufosinate.

DEVELOPMENT, APPROVALS AND REGISTRATIONS

The first approved field trials with transformed plants in 1989 prooved the stable integration and expression of the glufosinate ammonium resistance genes in plants. A number of further crops have since been transformed and tested. The major field crops oilseed rape, maize, soybeans and sugar beet were selected to be the first developed as glufosinate ammonium tolerant crops. After the approvals for field trials with modified crops were achieved, extensive field development programmes were started in 1990 in Canada, USA and in France. In the following years they have been tremendously extended in America and also to further countries in Europe as well as other regions. Results showed excellent crop safety and efficient broad spectrum weed control with dose rates of 300 - 600 g a.i. / ha. (Rasche *et al.*, 1995)

Registration of the selective herbicide use

Despite the fact that the herbicide glufosinate ammonium is registered and sold since several years in many countries the use as a selective herbicide in tolerant crops also needs to be registered almost like a new active ingredient. Therefore data on metabolism, toxicity, residues, field performance etc. had been generated for evaluation and approval by registration authorities. N-acetyl-L-glufosinate is non toxic, non allergenic, and rapidly and completely degraded in the soil as it is known for the active ingredient. For selective weed control glufosinate ammonium is registered under the brand name Liberty™. In spring 1995 Liberty was the first time registered in Canada for weed control in tolerant Canola. In spring 1997 Liberty was registered in the USA in tolerant maize and soybean varieties. In Europe registrations for Liberty in maize and oilseed rape are expected by the end of 1997. Further registrations in sugar beet and other crops and further countries will follow.

Variety development and approval

Leading seed companies and important breeding institiutions have entered into cooperation and license agreements. Superior transformants with the glufosinate ammonium tolerance are incorporated into germplasms. New varieties and hybrids are continously developed and adapted to different regions and market conditions. The seed companies finally register them and sell the glufosinate ammonium tolerant seeds. The seeds with the herbicide tolerance gene are the link to Liberty herbicide. AgrEvo therefore has chosen the trademark and logo Liberty Link™ to be used as a visual label on respective seed bags. In spring 1995 the Canadian authorities fully registered the first two Liberty Link Canola varieties for AgrEvo. In spring 1996 two Liberty Link Canola hybrids from PGS, Plant Genetic Systems, obtained full approvals in addition. In the USA, Liberty Link maize hybrids were fully approved in January 1997 for food and feed uses. In 1997, a large number of Liberty Link maize hybrids were grown for the first time throughout the corn belt in the United States. For the 1998 season Libery Link maize hybrids and oilseed rape hybrids are expected to be appoved in the EU.

STATUS OF MARKET INTRODUCTIONS AND EXPERIENCES

The Liberty Link system is an innovative weed control system with two partners - developed from a natural origin.

The varieties with the herbicide tolerance gene as the Link to Liberty

- top germplasms
- range of breeders
- range of crops

+

The herbicide Liberty for fast and broad spectrum weed control

- broad spectrum
- crop safety
- high flexibility
- unique mode of action

⇓

™ Novel weed control by AgrEvo

- Perfect combination of exceptional broad spectrum weed control with top varieties that´s the Liberty Link system.

<u>Liberty Link Canola - oilseed rape</u>

The Liberty Link system has been introduced the first time in Canada very successfully in spring 1995 with the Liberty Link Canola variety Innovator. However, in 1995 and 1996 Innovator was grown under a contract to crush closed loop, production system. Since international clearances were not in place at that time, this production system ensured that seed was kept within specific Canadian crushing plants to guarantee use in the domestic market only. In 1997, two Liberty Link varieties and two hybrids were available. As international clearances are in place in USA, Japan, UK and expected for the EU in autumn, Liberty Link canola will no longer be separated from conventional canola. Canadian farmers have fully accepted the Liberty Link system for use in canola. They have grown about 830.000 ha in 1997 (Table 1).

Table 1: Liberty Link canola (LL-canola) (planted area in k ha)

Variety	1995	1996	1997	
Canola	5300	4500	4800	e
LL-Canola	15	130	830	e

e = Estimates

If one considers the fact that Liberty Link canola is presently of the *Brassica napus* type only, which is ca. 60% of total canola grown, the market share of Liberty Link canola has already grown to about 30%. Evidence of the benefits of the Liberty Link system can be found in several areas. AgrEvo internal research, Agriculture and Agri-Food Canada federal government research, farmer experiences and feedback from the crushing industry all points to the benefits of the system:

- Improved germination with Liberty Link Canola
  By using Liberty, farmers can move away from pre-emergence herbicides with their associated problems. By avoiding tillage associated with pre-emergence herbicides, users of the Liberty Link system can maintain a moist firm seedbed that promotes better field germination and vigour.

- Less herbicide used
  By using Liberty on average with 400 g a.i./ha, farmers apply about 1 kg less total herbicide than is typical of the previously accepted canola growing practices involving the use of 1.400 kg a.i./ha trifluralin. At these rates the comparative costs are $ 30/ha for trifluralin and $ 52/ha for Liberty. The only other comparable post-emergent option is a three herbicide combination treatment of sethoxydim plus ethametsulfuron plus clopyralid at a total rate of 200 + 15 + 150 g a.i./ha at a cost of $ 135/ha (all figures in Canadian Dollars).

- Improved weed control for an affordable price
  Because the Liberty Link system controls more weeds than any other herbicide or combinations of herbicide programs, growers tended to use Liberty Link canola on a weedy piece of land, where they would otherwise not have been able to grow canola.

- Significantly increased yields
  Research by Canadian federal government researchers indicates a yield advantage associated with Liberty use compared to conventional post-emergence herbicides of approximately 9 %.

- More even maturation and less green seed
  Data from crushers involved in Innovator contract work, indicates that the Innovator harvest scored extremely well on crop grade due to less green seed and more even moisture content than traditional canola harvested from the same region in the same year.

In 1996 an Innovator grower survey was completed. The survey included 682 Innovator canola growers in Manitoba and Sasketchewan representing 43510 ha of the total Innovator canola grown in Canada.

Farmers are extremely satisfied with the Liberty Link production system

- 84 % will definitely use Liberty Link Canola and Liberty again
- 55 % of their total canola should be Liberty Link canola.

- 88 % stated one of the following as the main advantage using Liberty:
  - no soil incorporation
  - firm, moist seedbed
  - soil and moisture conservation

Targeted monitoring of some 1995 release sites regarding herbicide tolerant volunteers and weeds, was included voluntarily. Monitoring is non-destructive and uses an immunological-based test (ELISA) to identify herbicide tolerant individual plants. In-crop results confirm that herbicide tolerant volunteer plants occur at the same frequency as traditional canola volunteers. Farmer chosen weed control programs have been found to control all canola volunteers including herbicide tolerant volunteers. No herbicide tolerant weedy relatives have been found. Monitoring results from unmanaged areas adjacent to fields and along transportation corridors indicate volunteers in field margins only. Again, the frequency of volunteers equals that of traditional varieties. Work is continuing to determine if volunteer persist under these conditions. In short the results predicted by our earlier outcrossing, competitiveness and invasiveness studies have been substantiated: herbicide tolerant canola has no altered weed or invasiveness potentail compared to traditional canola varieties.

Liberty Link maize

In spring 1997 the Liberty Link system has been launched in maize the first time in the USA (Table 2).

Table 2: Liberty Link maize in USA (planted area in k ha)

Variety	1997 (Estimates
maize total	32.466
LL-maize	1.500

A large number of different maize hybrids from many seed companies have been grown. First reports from fields, where Liberty has been used, signaled very good performance of Liberty and Liberty Link maize in terms of weed control and crop safety. More evidence of the benefits of the Liberty Link system in maize will be come available. AgrEvo are confident, it will confirm the positive experience and promote the acceptance of the Liberty Link system in Europe and elsewhere.

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MANAGEMENT OF HERBICIDE TOLERANT CROPS IN EUROPE

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ABSTRACT

Herbicide tolerant crops are among the first transgenic plants ready to be marketed in Europe. The weed control strategy has to be re-designed by taking into account this new technology. While some weeds problems will certainly be made easier to solve, new concerns should be addressed. The cost-benefit analysis and the risk assessment must be carried out on a case-by-case basis and by taking into account several criteria. Multi-year and multi-crop monitoring studies suggest that a more integrated crop management should be required.

INTRODUCTION

After about 15 years of biotechnology research carried out by public research teams as well as private companies, the first marketing releases occurred in North America in 1995, while in Europe the first applications are still under discussion. Tobacco tolerant to bromoxynil, imports of glyphosate tolerant soybean, insect tolerant corn through the *Bt* strategy (insect tolerant) and a restricted permit for a herbicide tolerant hybrid sum up the current european status for genetically modified organism (GMO) marketing. Several other applications for marketing clearance have been submitted.

Corn, sugar beet and rapeseed are the main crops for which biotechnology has been applied. While several traits have been introduced (oil quality, disease and insect resistance) are under development, herbicide resistance has been developed extensively and three sytems are near marketing : glyphosate and glufosinate resistance for the three crops and bromoxynil resistance for rapeseed.

Development of transgenic plants raises several questions, most of them are not specific to recombinant DNA techniques : ethical concerns, relationship between science and society and organization of collective expertise, marketing of transgenic plants with new rules, protection of biotechnology and patent policy, food and feed safety of these novel plants, environmental and agronomic concerns. With respect to these last concerns, the evaluation has to be performed on a case-by-case basis. The risk assessment of gene flow must take into account the specific trait introduced (e.g. herbicide resistance vs oil quality), the biology of the plant (open vs self pollination, seed dormancy) and the agricultural context (cropping systems, spatial organization of the crops and agricultural practices).

Herbicide tolerance is not only one of the first traits for which marketing clearance has been required but it is also an adequate model to carry out the risk assessment of crop management of transgenic plants. In this paper the main criteria for consideration in herbicide tolerant crops and the effect of their use in cropping systems will be reviewed. Rapeseed provides a good example of the principles involved.

WEED CONTROL STATUS

The status of weed control differs depending on the crops. To sum up, sugar beet weed control is efficient but programs are expensive and require complex management. For corn, current programs are also efficient but most of them are based on the atrazine and new solutions avoiding this herbicide should be designed in the next future.

For rapeseed, weed control remains a major technical concern of crop management. Some weeds, especially wild relatives of rapeseed, are difficult to control and few post-emergence solutions are available. Although the effects of weed competition are difficult to establish and highly variable, we can estimate the mean yield losses to about 15 %. A survey performed in 1993 and 1994 in France (more than 10,000 fields surveyed) suggested an average weed control cost of about 400-450 FF per ha, which represents more than 25 % of the total inputs (Messéan *et al.*, 1995a). Weed control thus remains one of the main problems of rapeseed crop in Europe.

CRITERIA TO BE TAKEN INTO ACCOUNT

Weed control improvement

Weed control improvement. Herbicide tolerant varieties will be accepted by farmers only if there is a significant economic benefit in their use compared with standard solutions. Herbicide-tolerant crops appear to be more flexible for farmers : in those situations where one do not require any weed control, pre-emergence control could be avoided and weed control applied only if weeds are competitive. Furthermore, more efficient weed control due to a broader spectrum should induce an increase of yield and quality of rapeseed by limiting disease and pest pressure and more flexibility could be obtained in manpower and equipment organisation. However, such favourable effects still remain to be established.

New weed management

For rapeseed, new weeds will be produced through rapeseed volunteers and gene transfer to weeds (like *Sinapis* or *Raphanus*). Farmers will have to control them and to survey these new weeds which are less easy to identify than classical ones. Furthermore, current use of non selective herbicide like glyphosate or glufosinate (pre-sowing weed control or set-aside management) should be modified. It is thus necessary to design a global strategy when marketing such products.

Environment impact

Even if herbicide resistance does not avoid herbicide use, an integrated pest management strategy for weeds could lead to a decrease of herbicide used. Furthermore, the main herbicides involved in herbicide tolerant plants (glyphosate, glufosinate and bromoxynil) seem to have a good toxicological profile and be more environment-friendly.

Marketing of products

The strategy of the main users of oil and meal is not clearly established. Furthermore, regulation rules are not yet adopted. Systematic labeling of GMOs is still under discussion in the "Novel foods" regulation project. If systematic labeling were required, marketing of transgenic rapeseed would lead to specific collecting, transformation and distribution channels and thus to higher costs.

Public acceptance.

As the behaviour of the FlavSavr tomato demonstrated, public acceptance is not easily predictable. In the case of rapeseed, special emphasis should be given to its image. Improvement of its productivity and its competitivity (e.g. for industrial purposes) through developmenet of hybrids or genetic engineering is often related to higher level of inputs and higher environmental negative impact.

RISK ASSESSMENT

Several years, the main question with respect to modified rapeseed was: will the transgene be disseminated outside the field and be transferred to other plants and, especially, to weeds? From many studies carried out by different scientific teams, it can be concluded that transgenes will disseminate and can lead to outcrossing with weeds. Although interspecific crosses between rapeseed and related wild species lead to less fertile plants, they can produce a small quantity of seeds (Kerland *et al.*, 1994).

As we know that transgenes will disseminate, the question is now: So what? Could the consequences of such a dissemination be managed? With respect to long-term effects, no experiments are available for assessing the transgene behaviour. In order to estimate gen flow, simulations using genetic models are performed. These models generally represent the gene transfer from a field towards the wild species located at field edges and take into account various parameters such as the gene migration rate, its dominance level or the competitivity of the hybrid. Long-term behaviour appears to be difficult to predict as the model is highly dependent on specific events. It is thus necessary to take into account the spatial and temporal variability. On the other hand, we can look for markers already introduced into rapeseed in the past and to survey their behaviour in the non-cultivated areas. Such a survey is being performed in various regions of France, where we are intending to detect the introgression of traits like "low-erucic" in wild species.

Gene flow

In the case of rapeseed, gene flow can occur through two different ways :

* the pollen, either towards rapeseed plants (intraspecific crosses) or towards wild relatives which are quite numerous (interspecific crosses)

* the seeds, through volunteers in subsequent crops or seed dissemination during transportation.

The long-term effect of such phenomena on farmers' crop management of transgenic plants and the design of adequate agricultural practices are assessed by carrying out several types of studies :

* Modeling the gene flow. Models of gene flow between two adjacent fields have been designed (Reboud, 1992 ; Lavigne *et al.*, 1994) and are being improved by taking into account crop rotations, spatial patterns of crops and agricultural practices.

* Specific studies about outcrossing have been performed in order to estimate pollination distances and interspecific crosses (Jorgensen and Andersen, 1996 ; Kerlan *et al.*, 1992 ; Eber *et al.*, 1994 ; Baranger *et al.*, 1995). Pollination distances are quite large and outcrosses with wild relatives like wild radish or wild mustard can occur under natural conditions.

Other studies have been performed in North America and first large scale releases already took place there. However, climatic and agricultural conditions are quite different in Europe : shorter rotations (every two years in some european regions), winter type rather than spring type, different kinds of wild relatives. Thus, it appears to be rather difficult to extrapolate data from North America for assessing the agronomic interest of herbicide tolerant crops.

<u>A multi-crop and multi-year monitoring study</u>

In order to assess the effect of such outcrossing under agricultural conditions, in 1995, the French technical institutes, CETIOM, AGPM, ITB and ITCF, designed and implemented a monitoring study for various transgenic crops on three platforms located in different regions of France : Champagne, Burgundy and Midi-Pyrénées (South-West). Each platform consists of a 6 ha field where transgenic corn, rapeseed and sugar beet are cropped with the usual local cropping system (Figure 1). The transgenic traits are as follows :

* glufosinate and glyphosate resistance for corn, rapeseed and sugar beet ;

* bromoxynil resistance for rapeseed and corn borer tolerance (using the Bt system) for corn.

A 500 meter area around the field was defined and monitored in order to assess the spatial impact of transgenic crops.

This three-year experiment aimed mainly at :

* assessing the impact of these transgenic crops when cultivated together in the same field area

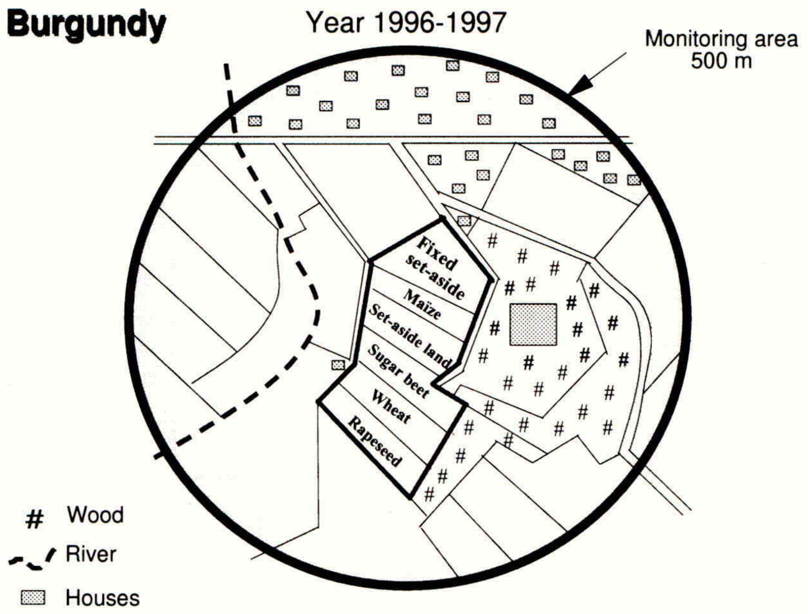
* designing the weed control of volunteers in subsequent crops which are tolerant to the same herbicide (e.g. glyphosate-tolerant rapeseed volunteers in the subsequent sugar beet tolerant to glyphosate)

* evaluating the multiple resistance rate when cropping two adjacent rapeseed fields with two different herbicide resistances

* estimating the interspecific outcrossing towards the wild relatives under real and local conditions and

* estimating the cost-benefit of herbicide resistance technology with respect to conventional techniques.

Figure 1 - Example of a cropping system in Burgundy (1995-96) using transgenic traits.



Example of cropping system, Burgundy

Year 1995-1996	**Set-aside land**	**Rapeseed**	**Wheat**	**Sugar-beet**	**Maïze**	**Fixed set-aside land (trefoil)**
Year 1996-1997	**Rapeseed**	**Wheat**	**Sugar-beet**	**Wheat**	**Maïze**	**Fixed set-aside land (trefoil)**
Year 1997-1998	**Set-aside land**	**Sugar-beet**	**Set-aside land**	**Rapeseed**	**Maïze**	**Fixed set-aside land (trefoil)**

Outcrossing with wild relatives

Within the monitoring area, each wild relative plant of rapeseed was located and surveyed until seed maturity. The flowering period was observed and compared with the flowering periods of the transgenic rapeseed crops. Seeds were sampled for assessing the herbicide resistance which was checked by spraying herbicides after re-sowing. Table 1 gives the occurrence of wild relatives observed during the first year of the study (1996) : a plot represents one or several plant(-s) located at the same place.

Table 1 - Identification of wild relatives within the monitoring area in 1996.

Location		Weed species and number of samples	
		Rapeseed plot	Other crops and survey zone
Midi-Pyrénées		*Sinapis arvensis - 1* *Rapistrum rugosum - 35* *Brassica nigra - 3*	*Sinapis arvensis - 4* *Rapistrum rugosum - 1* *Brassica nigra - 38* *Sinapis alba - 21*
	Total	39 samples	64 samples
Burgundy		*Sinapis arvensis - 12*	*Sinapis arvensis - 30* *Rapeseed volunteers - 1* *Arabidopsis thaliana - 1* *Capsella bursa pastoris - 1*
	Total	12 samples	33 samples
Champagne-Ardennes		No compatible weed	*Rapeseed volunteers - 20* *Sinapis arvensis - 5* *Sinapis alba - 4* *Raphanus raphanistrum - 1*
	Total	0	30 samples
Total		51 samples	127 samples

Preliminary results indicated that no herbicide resistance with wild mustard and other mustard species occurred during this first year. Unfortunately, wild radish was not present in our situations and specific location sites should be found in future. The ensuring following years will allow us to increase the precision of the estimated frequency of outcrossing.

Multiple resistance

The three herbicide tolerant rapeseed varieties were cropped in adjacent fields and double tolerant plants were detected in two different ways :

* by applying the herbicides on volunteers whose emergence occurred after harvesting ;
* by sampling seeds and re-sowing using a specific design of experiments and direct application.

Both methods gave similar results with respect to the rate of double resistance. Although the results were depending upon the variety, the average rate of double resistance can be estimated under our specific conditions : about 2 % at a one meter distance, 0.2 % at 20 meters and less than 0.01 % at 65 meters. Although further data are still required, these results seem to indicate that multiple resistance should probably be the major concern for farmers rather than interspecific crosses.

CONCLUSIONS

The preliminary results obtained during the first year of the project confirmed what was expected from previous studies. Thus results have been obtained under current farmer practices and provided data which will be used to fit simulation models for gene flow. Further experimental sites will be necessary in order to enhance the range of agricultural conditions and observations of long-term effects will require several years. Practical recommendations for crop management by farmers are expected.

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NORTH AMERICAN DEVELOPMENTS IN HERBICIDE TOLERANT CROPS

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ABSTRACT

The use of herbicide tolerant crops in North America has focused primarily on corn, soybean, and canola. While there have been a number of herbicide tolerant cropsavailable for several years, grower adoption of this technology has been somewhat slower than anticipated. However, with the availability of glyphosate-resistant soybeans and canola and imidazolinone-resistant corn and canola, and the marketing emphasis that companies will place on these products, utilization will likely increase dramatically. Objectively, when considering the use of herbicide-tolerant corn or soybeans, and the appropriate herbicide, weed management is not conceptually different than where traditional crop varieties and herbicide programs are used. However, farmer expectations are considerably greater with the new technology compared to existing crops and herbicide treatments. Farmers generally have failed to recognize the changes in management skills required to effectively use the herbicide tolerant crops. While the herbicide tolerant crops may have some advantages compared to current practices, their use also results in acceptance of risks associated with the technology.

INTRODUCTION

Bridges (1994) suggested that weeds represent the most important pest complex and estimated that the impact of weeds on the United States economy exceeds $20 billion annually. Holt (1994) warned of a general lack of research to support the development of alternative weed management strategies and pointed out the problems of current herbicide use. The use of herbicides has created considerable controversy in the United States. Strange and Miller (1994) suggest that the chemical dependency of modern agriculture has caused the decay of rural America and presented evidence that many farmers believe that there is too great a reliance on herbicides. Advocates of herbicide tolerant crops suggest that this technology is no different than that currently utilized for weed control, but does offer economic and environmental advantages (Burnside, 1996). Others strongly indicate that herbicide tolerant crops and the resultant use of herbicides are major environmental, economic and ecological concerns and recommend the implementation of sweeping restrictions to limit the adoption of the technology (Goldburg et al., 1990).

It is the intent of this paper to review the current status of herbicide tolerant crops in North American agriculture. The benefits and risks of the technology will be objectively reported and successes and problems associated with herbicide tolerant crops discussed. Several views will be taken; the implications of herbicide tolerant crops on weed management systems will be reviewed, how herbicide tolerant crops impact agriculture ecologically will be considered, and farmer expectations of herbicide tolerant crops documented.

WEED MANAGEMENT AND HERBICIDE TOLERANT CROPS

Industry has developed a number of herbicide tolerant crops including canola, sunflower, cotton, corn, and soybean. Research has been conduct on many more crop species and with a great number of herbicides (Dyer, 1996). Wilcut *et al.* (1996) suggest that herbicide-tolerant crops will be advantageous for weed management even if effective herbicides are already available. Do herbicide-tolerant crops represent a different strategy for weed management? Coble (1994) stresses the need for weed thresholds (economic thresholds) thus facilitating the use of herbicides only when needed to protect crop yields. Hess (1996) indicates that the risks associated with an integrated weed management system based on herbicide-tolerant crops are due to a lack of knowledge about the ecology and biology of the crop and associated weeds. Farmer expectations for weed control are greater than what the use of these strategies, in conjunction with herbicide-tolerant crops, will provide.

Experiences in the Midwest indicate that herbicide resistant weed populations are rapidly expanding and farmers are not managing the problem. Proponents of herbicide-tolerant crops suggest that this technology will improve management options to deter the development of herbicide resistance in weeds (Wilcut *et al.*, 1996, Burnside, 1996). The author suggests that herbicide-tolerant crops and the resultant use of specific herbicides will increase the potential for the development of resistant weed populations, but the technology could also be used effectively to deter weed resistance. Even if, as suggested by the industry, there is little potential for resistance to glyphosate to develop in weed populations (Anon., 1997), selection will still occur resulting in weed populations that are not effectively managed by the herbicide (Radosevich & Holt, 1984).

Herbicide-tolerant crops do represent a potential weed problem to rotational crops. For example, corn hybrids that are tolerant to sethoxydim (SR varieties) have been difficult to manage in soybeans. However, with appropriate planning, volunteer herbicide-tolerant crops should be rather easy to management in rotational crops if the appropriate herbicide systems is used.

Ideally, herbicide-tolerant crops will improve the use of alternative weed management strategies. Wyse (1992) and Burnside (1996) suggest that herbicide-tolerant crop technology will increase the utilization of alternative strategies for weed management. However, a recent survey conducted by the Weed Issue Team at Iowa State University, and supported by the Leopold Center for Sustainable Agriculture, demonstrates clearly that it is unlikely that herbicide-tolerant crop technology will increase the use of alternative weed management strategies.

FARMER EXPECTATIONS FROM HERBICIDE-TOLERANT CROPS

Farmers have expectations for weed control that are unreasonable from an environmental, ecological, and economic perspective. The herbicide industry has done an effective job of educating farmers about the level of weed control herbicides will provide and the consistency that this level of efficacy will be delivered. As a result, farmers have "learned" that weed control is synonymous with weed-free and a zero-tolerance for weed escapes now exists in much of the Midwest. The use of herbicide-tolerant crops is thought by farmers to dramatically improve weed control and potentially reduce costs. Competition among seed companies and the demand for new products has resulted in claims that herbicide-tolerant crops will allow better and more effective weed control (Duvick, 1996). Glyphosate-tolerant crops are positioned as the answer to all weed problems (Anon., 1997). A new prepackage herbicide combination of imazethapyr and imazapyr is promoted to control woolly cupgrass (*Eriochola villosa*) when used in conjunction with imidazolinone tolerant corn hybrids. These claims are made because of a competitive market place and farmers expect that herbicide tolerant crops will control weeds more effectively. Attempts to control weeds at a level expected by farmers is possible, but not without increased economic and environmental risks.

The expectation by farmers that herbicide-tolerant crops will improve potential yields, and thus economics, by eliminating risks of weed interference is not likely to be realized. Economic models suggest that herbicide-tolerant crops will not likely impact the economics of crop production (Tauer & Love, 1989). Typically, the level of weed control provided by herbicide-tolerant crop management systems is equal, but no better than conventional systems. Farmers also expect weed control costs to be reduced when herbicide-tolerant crop management systems are used. Experience in Iowa suggests that the cost of weed control with the new technology is similar to existing systems.

HERBICIDE-TOLERANT CROPS AND HERBICIDE DRIFT

Concerns have been expressed about the use of herbicide-tolerant crops and the increased risk of herbicide drift (Owen, 1994, Owen, 1997). However, given the high use of herbicides in agriculture, the increased potential for herbicide drift resulting from the use of herbicide-tolerant crops is minor. Drift is an inevitable consequence of current application techniques: all herbicides will drift. However, there is some concern associated with the herbicides that are used with herbicide-tolerant crops, and the increased number of applications likely necessary with some of these herbicides to meet weed control expectations. In Iowa, herbicide drift complaints were higher in 1997 than in past years (Charles Eckerman, Iowa Department of Agriculture and Land Stewardship, personal communication). The increased use of herbicide-tolerant crops and the resultant herbicide applications possibly contributed to this increase.

HERBICIDE-TOLERANT CROPS AND HERBICIDE CARRYOVER

It has been argued the use of herbicide-tolerant crops and the resultant herbicides will increase the amount of herbicides applied to a field (Goldburg *et al.*, 1990). However, given that the costs of the herbicides is similar to conventional systems, the concern for excessive amounts of these herbicides to be applied is unfounded.

However, herbicide carryover is a frequent problem in Midwest agriculture (Curran *et al.*, 1991). Wrubel and Gressel (1994) estimate that 64% of the soybeans in the United State receive applications of ALS inhibitor herbicide classes. While the percentage corn treated with these herbicides is lower, the number is increasing rapidly. Given the residual characteristics of some ALS inhibitor herbicides and the lack of tolerance that rotational crops demonstrate to these herbicides, and the high usage, carryover is a significant concern. The use of herbicide-tolerant crops such as imidazolinone-tolerant corn hybrids and sulfonylurea-tolerant soybean provides an opportunity to manage the potential carryover problems and may be an excellent use of this technology (Owen, 1994).

EXPERIENCES WITH HERBICIDE-TOLERANT CROPS

While research has been conducted on a number of different crops, those that have engineered herbicide tolerance and currently with the greatest economic importance in North America are corn, soybean, and canola (Dyer, 1996, Re *et al.*, 1996). One of the most important problems anticipated with the use of herbicide-tolerant crops was experienced in 1997. While it is intuitively obvious that only the herbicide-tolerant crop should be treated with the herbicide and not the sensitive crop, there were many examples of this type of mistake in North America. Corn that was not tolerant to sethoxydim was treated with sethoxydim, hybrids that were not imidazolinone-tolerant were treated with the prepackage mixture of imidazolinone herbicides, and glyphosate was applied to sensitive soybean varieties. In all cases, these mistakes were economically disastrous. There is a need for better communication between the applicator and the farmer.

Herbicide-tolerant corn

Currently in the Midwest, there are three herbicides for which engineered herbicide-tolerant hybrids exist; glufosinate-tolerant, imidazolinone-tolerant, sethoxydim-tolerant corn hybrids are commercially available. The imidazolinone-tolerant hybrids are most widely available and have the greatest marketing effort. Glyphosate-tolerant corn hybrids have been evaluated in the field for several years, but are not available for commercial use.

Glufosinate-tolerant corn, in conjunction with glufosinate, were positioned as a strategy to manage problem weeds and for use in no tillage production systems. Often, the glufosinate was applied in combination with a residual herbicide. Farmer success was varied, depending on the management skills and expectations. Performance of glufosinate-based systems in Iowa State University research was variable depending on the level of weed infestation and environmental conditions. American Cyanamid has launched an aggressive marketing campaign for the use of imidazolinone herbicides in imidazolinone-tolerant corn and has registered a number of prepackage herbicide mixtures for use in imidazolinone-tolerant corn. American Cyanamid has actively positioned these products with a strong emphasis on the management of resistant weed populations which may result from the use of imidazolinone herbicides.

While these combinations include a herbicide with a different mode of action, with the exception of imazethapyr plus imazapyr, there is some question whether or not this strategy has value in reducing the potential for resistant weed populations (Wrubel & Gressel, 1994). The occurrence of imidazolinone-resistant weeds in Iowa increases and the use of imidazolinone herbicides in both corn and soybeans will contribute to the problem (Robert G. Hartzler, Iowa State University, personal communication).

The acceptance of imidazolinone herbicides for weed control in imidazolinone-tolerant corn has not been widely successful to date. However, the new combination of imazethapyr plus imazapyr demonstrates excellent activity on specific problems weeds, such as woolly cupgrass, that may increase farmer use of this technology. However, there has also been occasional fields of imidazolinone-tolerant corn that have exhibited herbicide injury at an unacceptable level. Observations at Iowa State University suggest that a number of factors are involved, including environmental stress and other agronomic characteristics of the specific hybrid. However, it is apparent that the cross-resistance to different imidazolinone herbicides may not be consistent and injury may occur from these herbicides applied topically at rates currently used.

The use of imidazolinone-tolerant hybrids has been suggested as a strategy that, in part, may lessen the impact of ALS inhibitor herbicide carryover. While the level of cross-resistance that is demonstrated by the tolerant hybrids may vary, it should be sufficiently high enough to lessen the occurrence of injury (Owen, 1997).

Sethoxydim-tolerant corn hybrids were available on a limited basis in 1996 and 1997. This technology was positioned as a strategy to control specific weeds such as woolly cupgrass, wild proso millet (*Panicum miliaceum*), and quackgrass (*Agropyron repens*). Generally, the results of this technology have been good, although often not as effective, given the biological characteristics of the target weed, to meet farmer expectations. Iowa State University positions the use of sethoxydim-tolerant corn hybrids and sethoxydim as an important component in a woolly cupgrass management program but not the answer.

Volunteer sethoxydim-tolerant corn from 1996 was a problem in 1997 soybean fields. These hybrids demonstrate some cross-tolerance to other aryloxyphenoxypropionate and cyclohexanedione herbicides and farmers how attempted to use these products did not control the volunteer weed at a level to meet expectations.

Herbicide-tolerant soybeans

Currently, there are three herbicides for which herbicide-tolerant soybean are commercially available. These include glyphosate and the sulfonylureas chlorimuron and thifensulfuron. Glufosinate-tolerant soybean varieties will be available in the near future. Of these, the glyphosate-tolerant soybeans has generated the greatest interest in farmers.

Glyphosate-tolerant soybean varieties are viewed by farmers as the answer to all weed management problems. Monsanto has positioned this technology in no tillage and narrow row spacing systems and farmers presume that it will eliminate all risks associated with weed control. In 1996, in Iowa planting was very late and, as a result most of the postemergence herbicide applications were applied in late June and July. At this time, most of the weed germination events had occurred and a single application of a postemergence herbicide was generally effective.

In 1997, planting occurred early and weed germination required an earlier application of the postemergence treatments. In many instances, unless alternative weed management was included, second and third applications were considered necessary by farmers. Glyphosate-tolerant soybeans allowed these later applications. Experiences in 1997 suggest that better management skills are required and often second applications may be needed for glyphosate-based weed control systems.

Most of the herbicides in the Midwest are applied by commercial applicators. Concerns about glyphosate drift may have seriously affected the timeliness of many applications in 1997. Further, the commercial applicators were expected to make the application timing decisions in many instances. The amount of time required to make these management decisions created a problem for the commercial applicators.

The issue of yield potential with glyphosate-tolerant soybean varieties was also a point of discussion. It is suggested that there is no loss of genetic yield potential with the glyphosate-tolerant soybean varieties (Harper, 1997) yet farmer complaints from 1996 experiences were in evidence. Further investigation suggests that many of the reported "low" yields were attributable to delayed glyphosate applications resulting in weed interference. As with all postemergence herbicide systems, management skills are important. The understanding of crop/weed interaction, the impact of the environment on plant development, and the implications of weed populations on potential crop loss are critically important for maximizing yield potential; these are not simple strategies!

One of criticisms about weed management programs based on a single herbicide is the potential for select resistant weed populations (Duke *et al.*, 1991). Monsanto has suggested that due to the mechanism of action, weed resistance will not occur (Anon., 1997). Weed scientist have cautioned that regardless of whether or not resistance in weeds does develop, population shifts to weeds that are more tolerant to a particular herbicide or "avoid" the strategy are likely (Holt, 1994).

Experiences in Iowa during 1997 suggest that these population shifts can occur rapidly. Common waterhemp (*Amaranthus rudis*) populations demonstrate delayed germination and have "avoided" planned glyphosate applications. Velvetleaf (*Abutilon theophrasti*) demonstrates greater tolerance to glyphosate and farmers are reporting problems controlling this weed with the rates of glyphosate for which they are willing to pay.

Sulfonylurea-tolerant soybeans have been commercially available for several years. DuPont specifically created prepackage mixtures of chlorimuron ethyl and thifensulfuron methyl that had elevated rates thus improving the weed spectrum. On traditional soybean varieties, these prepackage mixtures did not provide sufficient crop safety. However, dramatic increase in common waterhemp across the Midwest and the occurrence of ALS inhibitor resistance in some of these populations may have limited the farmer acceptance of this system. Further, the implications of elevated chlorimuron ethyl rates, high pH soil types, and resultant concerns for herbicide carryover to rotational corn do not favor the use of sulfonylurea-tolerant soybeans and the prepackage herbicide mixtures. Regardless, these systems have been used to some extent in Iowa.

Another use of the sulfonylurea-tolerant herbicide may be to lessen the negative impact of prosulfuron carryover from corn to soybeans. Prosulfuron is a sulfonylurea herbicide marketed by Novartis for postemergence weed control in corn. Prosulfuron has a relatively long soil residual, particularly in high pH soil (M. Johnson, Novartis, personal communication) and has caused injury and yield reduction to rotational soybeans. The use of sulfonylurea-tolerant soybeans instead of traditional varieties has promise to minimize this problem (M. Vogt, Iowa State University, personal communication).

Herbicide-tolerant canola

Weeds represent one of the most important factors limiting canola production. A number of weeds are not effectively controlled by the available herbicides and changes in tillage and cultural practices are resulting in weed population shifts thus increasing the weed management problems (Darwent, 1994, A. Green, American Cyanamid, personal communication). Herbicide-tolerant canola is thought to provide a solution to many of these problems.

Triazine-tolerant canola cultivars were developed thus allowing the use of triazine herbicides. However, these cultivars do not have the same yield potential as other cultivars and have not been widely used (Wall, 1992). However the development of glyphosate-tolerant, glufosinate-tolerant, and imidazolinone-tolerant canola cultivars represents a major advancement in weed management (Shaw, 1997).

Harker (1997) suggested that the use of glyphosate-tolerant and imidazolinone-tolerant canola cultivars may increase the risk of selecting for resistant weed populations because these herbicides are used extensively in other western Canada cropping systems. However, he indicates that glufosinate will not be registered for use other than in glufosinate-tolerant canola and thus represents a good tool for weed resistance management. Darwent (1994) cautioned that there is a potential for the transfer of the herbicide tolerant trait to weedy mustards.

Shaw (1997) suggested that farmers approach this technology with guarded optimism. He stated that there may be economic benefits from the herbicide-tolerant canola in the form of control of problem weeds, fewer field operations, and improved grain quality. However, growers are concerned with the delays in food safety approvals by other countries, weed resistance, and technology fees. Importantly, there does not appear to be an agronomic difference in yield potential when herbicide-tolerant and traditional canola cultivars are compared.

One interesting development with herbicide-tolerant canolas was the recall by Limagrain of two glyphosate-tolerant seed varieties, LG3315 and LG3295 (Leite, 1997). These varieties apparently had an unregistered construct of the glyphosate-tolerance gene which was discovered during a quality control program. Canola seed for an estimated 245,000 ha was recalled and destroyed just prior to the 1997 planting season (R Holm, Univ. of Saskatchewan, personal communication). This may result in more of the imidazolinone-tolerant and glufosinate-tolerant canola used than the glyphosate-tolerant cultivars.

CONCLUSIONS

Herbicide tolerant crops are not yet planted on a significant number of acres in North American. However, with the increasing availability of crops tolerant to herbicides such as glyphosate, glufosinate, imidazolinones, sethoxydim and sulfonylureas, they will become an important part of weed management strategies. Further, the agricultural chemical industry and seed companies see herbicide tolerant crops as an important source of profits. Farmers have extremely high expectations for weed control resulting from the herbicide tolerant crop systems. Importantly, the use of herbicide tolerant crops and appropriate herbicides is perceived to require lower management than conventional weed management strategies. Evidence suggests this is not the case.

Proponents suggest that there will be increased use of alternative management strategies as a result of the herbicide tolerant crop systems. However, given farmer expectations and marketing strategies, it is unlikely that alternative strategies will be used, and in fact, a greater reliance placed upon herbicides for weed control. When considered objectively, the use of herbicide tolerant crops as a weed management strategy does not differ greatly from current strategies.

Herbicide tolerant crops have some risks associated with the use of this technology. Weed resistance, misapplication, herbicide drift, and the need for timely application all must be considered as potential problems for herbicide tolerant crop technology. However, these same risks are associated with conventional weed management systems. Benefits of herbicide tolerant crops focus on the potential for consistent weed control in conservation tillage systems, the use of herbicides positioned as environmentally safe, and less crop injury. Whether the benefits are more important than the risks associated with herbicide tolerant crops will be determined by farmers and their acceptance of this technology.

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