POSTER SESSION 8C

BIODIVERSITY, GENETIC MODIFICATION AND THE ENVIRONMENT

Session Organiser	Dr N McRoberts *SAC, Auchincruive, UK*
Poster Papers	8C-1 to 8C-10

Results of national weed surveys in arable land during the past 50 years in Hungary

Á Tóth
Plant Health and Soil Conservation Station, Budapest, 1118 Budapest, Budaörsi üt 141-145, Hungary

G Benécs-Bárdi
Plant Health and Soil Conservation Station, 2100 Gödöllö Koltán S. u.3., Hungary

Gy Balzás
Cyanamid Hungary Ltd., 1133 Budapest, Váci üt 110, Hungary

ABSTRACT

The change of political regime in Hungary in 1990 has caused significant modifications in the conditions of agricultural production and businesses. At present family (small) farming systems are account for some 25-30% of the cropping area while 2-3% of the total area is uncultivated. This situation has influenced the weed population of cultivated land; both cover and the distribution of some weed species have considerably increased. These results were demonstrated in an earlier publication (Tóth *et al.*, 1997) which considered the results of four surveys conducted between 1950 and 1997 in winter wheat and maize in which 202 locations were surveyed. The primary aim of our work has been to help Hungarian farmers develop regional weed management programmes suited to local weed populations. In order to produce management programmes that will take account of local conditions we have begun to examine the national weed survey data in detail, paying particular attention to variations in soil type. Results are presented for three different agricultural regions that inculde 17 soil types or sub-types.

INTRODUCTION

It is now well established that on regularly cultivated areas in Hungary two main types of weed vegetation develop annually; one associated with densely sown cereals and a second associated with row crops. The weed population characteristic of densely sown cereals is richest in winter wheat, while that of row crops is best developed in maize. Weed survey data recorded at a site which include assessments made in winter wheat, maize and in wheat stubble give an almost complete picture of the whole weed spectrum for that particular site. Such knowledge of the weed population in agricultural areas is essential from biological, crop production and weed control viewpoints both for farmers and agricultural scientists.
The research necessary to obtain such weed population data was initiated in Hungary in 1947 by Dr Miklós Újvárosi who carried out the development work that led to the first survey in 1949/50. Since that time, surveys have been conducted in 1969/70, 1987/88 and 1996/97. After the initial one, all of the surveys have been conducted by weed scientists from county plant health and soil conservation stations who have been trained previously according to a uniform system.

In this paper we present results that demonstrate changes in abundance and relative importance of several weed species over the 50 year period of the national weed survey and, using data from the 1996/97 survey, illustrate the inter-regional variation in the weed population among three regions with varying soil types.

MATERIALS AND METHODS

Sample sites for the 1996/97 survey were selected to provide a representative sample of regions that were known to vary in production practices and soil types and that were identified for their national importance in previous work. In total 202 locations were sampled covering 17 soil types or sub-types. The diversity of soil types in Hungary is illustrated in Figure 1.

At each location 10 sites were suveyed. At each site a 5m x 5m area was sampled according to the method of Balzás-Újvárosi in which the total percentage gound cover for each species present is estimated and recorded. All surveyed areas were herbicide free.

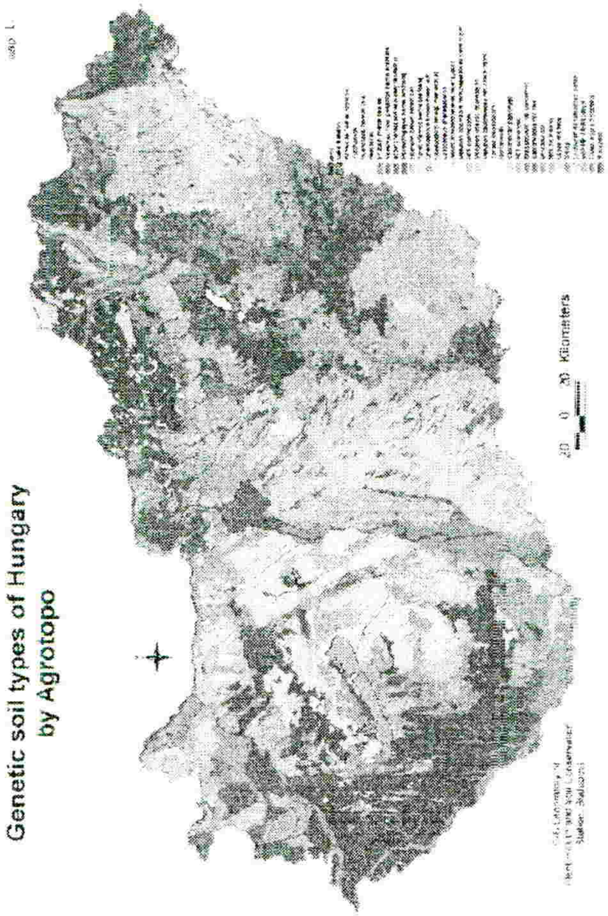

Figure 1. Variation in soil types in Hungary

RESULTS AND DISCUSSION

The first three national surveys were conducted at intervals of approximately 20 years and there was some debate prior to the 1996/97 survey as to whether changes in the weed population would be detected between the third and fourth surveys, given an interval of only 9 years. However, the impression gained from crop walking was that the weed population present in 1996/97 was different from that reported in 1988, and the full survey was condcuted as planned. The numerical data collected in the 1996/97 survey confirmed that significant changes in the absolute abundance and ranking of weed species, as estimated by percentage ground cover, had occurred between 1988 and 1997 (Table 1.)

Several weed species showed dramatic increases in abundance between 1988 and 1997, including *Ambrosia artemisifolia*, *Datura stramomium* and *Xanthium strumarium*, and among the annual monocots, *Panicum miliaceum*. Similar increases were also noted for perennial species such as *Cirsium arvense*, *Sorghum halepense* and *Elymus repens*. It was observed that not only had the listed species increased in relative importance (*i.e.* had increased their rankings among the species present) they had, in some cases, doubled their mean percentage cover on a national basis. Of particular concern for weed control at a national level was the finding that the trend for decreasing abundance in perennial weeds, noted during earlier studies, had apparently stopped or perhaps even reversed (Figure 2).
In more detailed analyses of the 1997 data, according to our objective of developing weed management programmes, we examined the differences between the weed populations of densely sown cereal crops (wheat) and row crops (maize) and the averaged figures. These results are shown in Table 2.

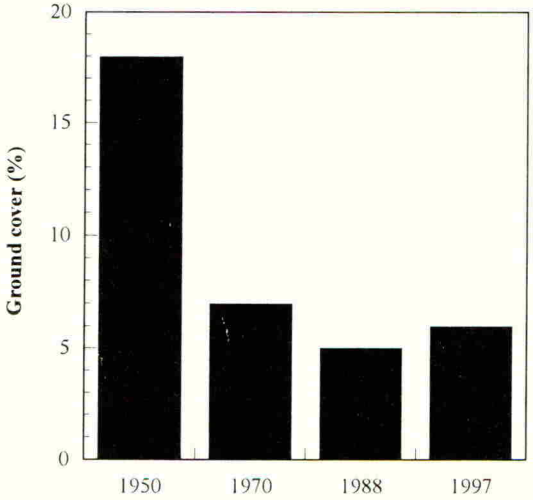

Figure 2. Mean percentage ground cover of perennial weeds in national weed surveys in Hungary between 1950 and 1997.

Table 1. The 20 most important weed species in national weed surveys in Hungary between 1950 and 1997 according to their rank importance in 1997

Weed Species	1950		1970		1988		1997	
	Rank	Mean % cover	Rank	Mean % cover	Rank	Mean % cover	Rank	Mean % cover
Ambrosia artemisifolia	21	0.39	8	0.87	4	2.57	1	4.70
Echinochloa crus-galli P.B. Va	9	0.86	1	3.73	1	4.42	2	3.91
Amarathus retroflexus L.	17	0.51	5	1.47	3	3.06	3	3.63
Chenopodium album L.	3	1.53	3	2.07	2	3.08	4	2.90
Cirsium arvense (L.) Scop.	2	2.00	7	1.12	8	0.71	5	1.81
Matricaria inodora L.	66	0.07	26	0.23	6	1.30	6	1.54
Convuluvulus arvensis L.	1	7.93	2	2.51	5	1.94	7	1.45
Datura stramomium	177	<0.01	59	0.06	19	0.38	8	1.07
Amaranthus chlorostachys Wi.	105	0.02	18	0.39	13	0.57	9	0.94
Galium aparine L.	137	0.01	50	0.09	12	0.59	10	0.87
Sorghum halapense	*	*	94	0.02	18	0.40	11	0.82
Elymus repens (L.) Gould	27	0.28	12	0.51	20	0.38	12	0.65
Panicum miliaceum L.	199	<0.01	192	<0.01	23	0.29	13	0.60
Xanthium strumarium L. Ssp. St.	130	0.01	113	0.01	24	0.27	14	0.57
Ploygonum lapathifolium L.	29	0.25	16	0.40	10	0.61	15	0.53
Bilderdykia convulvulus L.	14	0.71	6	1.14	11	0.60	16	0.52
Apera spica-venti (L.) Beauv.	56	0.08	36	0.14	14	0.46	17	0.49
Helianthus annuus L.	206	<0.01	119	0.01	16	0.42	18	0.49
Setaria glauca (L.) P.Beauv.	7	1.10	4	1.95	7	0.72	19	0.49
Papaver rhoeas L.	24	0.35	21	0.32	15	0.43	20	0.47

Table 2. Characteristic weed populations in wheat, maize and wheat stubble compared with national average (wheat and maize combined) figures in Hungary in 1997

Weed Species*	National average Rank	National average Mean % cover	Wheat Rank	Wheat Mean % cover	Maize Rank	Maize Mean % cover	Wheat stubble Rank	Wheat stubble Mean % cover
A. artemisifolia	1	4.70	4	1.60	1	7.77	1	7.48
E.crus-galli	2	3.91	28	0.14	2	7.67	3	2.08
A.retroflexus	3	3.63	37	0.10	3	7.16	7	1.60
C. album	4	2.90	5	1.24	4	4.55	2	3.85
C.arvense	5	1.81	2	1.84	8	1.77	4	1.87
M.inodora	6	1.54	1	2.80	24	0.29	6	1.68
C.arvensis	7	1.45	6	1.03	6	1.87	9	1.33
D. stramomium	8	1.07	55	0.05	5	2.09	14	0.54
A.chlorostachys	9	0.94	83	0.02	7	1.87	24	0.26
G.aparine	10	0.87	3	1.70	56	0.05	25	0.25
S.halapense	11	0.82	46	0.07	9	1.57	12	0.62
E.repens	12	0.65	13	0.43	14	0.87	13	0.59
P.miliaceum	13	0.60	130	0.01	10	1.20	34	0.14
X.strumarium	14	0.57	44	0.08	11	1.07	17	0.37
P.lapathifolium	15	0.53	27	0.15	13	0.91	16	0.42
B.convulvulus	16	0.52	10	0.62	21	0.42	10	1.00
A.spica-venti	17	0.49	7	0.98	154	<0.01	31	0.17
H.annuus	18	0.49	12	0.52	18	0.45	15	0.44
S.glauca	19	0.49	67	0.03	12	0.94	8	1.49
P.rhoeas	20	0.47	8	0.92	91	0.01	75	0.03

*full binomials are given in Table 1.

Table 3. Weed populations from three different regions compared with national average figures in Hungary in 1997

Weed Species	National average Rank	National average Mean % cover	Transdanubia Rank	Transdanubia Mean % cover	Great Plain Rank	Great Plain Mean % cover	Northern mountains Rank	Northern mountains Mean % cover
A. artemisifolia	1	4.70	1	6.40	2	4.35	14	0.60
E.crus-galli	2	3.91	2	2.80	3	4.07	1	6.98
A.retroflexus	3	3.63	4	2.23	1	4.94	6	2.63
C. album	4	2.90	3	2.45	4	3.29	5	2.81
C.arvense	5	1.81	5	1.54	5	1.78	4	2.90
M.inodora	6	1.54	6	1.33	7	1.35	3	3.10
C.arvensis	7	1.45	9	1.08	6	1.37	2	3.10
D. stramomium	8	1.07	8	1.09	8	1.27	41	0.12
A.chlorostachys	9	0.94	15	0.61	11	0.93	7	2.14
G.aparine	10	0.87	16	0.61	12	0.89	8	1.79
S.halapense	11	0.82	13	0.64	9	1.15	*	*
E.repens	12	0.65	14	0.62	18	0.44	9	1.65
P.miliaceum	13	0.60	7	1.31	39	0.16	36	0.16
X.strumarium	14	0.57	26	0.22	10	0.95	37	0.14
P.lapathifolium	15	0.53	10	0.78	26	0.28	13	0.74
B.convulvulus	16	0.52	18	0.48	15	0.58	17	0.41
A.spica-venti	17	0.49	11	0.69	23	0.31	15	0.56
H.annuus	18	0.49	12	0.65	19	0.43	33	0.18
S.glauca	19	0.49	23	0.26	16	0.49	11	1.22
P.rhoeas	20	0.47	22	0.31	13	0.64	20	0.36

The results in Table 2 show that while many of the 20 most abundant weed species nationally were common to all three cropping situations studied, there were several that showed considerable variation between cropping situations; for example, *Amaranthus chlorostachys*, *Panicum miliaceum*, *Apera spica-venti* and *Setaria glauca*. The results presented in Table 3 indicate the variation in weed populations that occurs between regions. While most of the species ranked in the top 20 nationally were also in the top 20-30 species in each region, some individual species showed large variation in relative abundance between regions. For example *Ambrosia artemisifolia* was the most abundant weed in Transdanubia (6.40% cover) and ranked second in the Great Plain (4.35% cover), but was only the 14th most abundant weed in the Northern mountains (0.60% cover).

The results presented here show that continued development of weed control programmes is needed if the reductions in weed infestation achieved in between the 1950s and 1970s are not to be lost and also that such developments should ideally be optimized for different geographical and cropping situations.

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Biodiversity of the seed bank of a herb-rich meadow and an adjacent field

H. Connolly and R. E. L. Naylor
Department of Agriculture, University of Aberdeen, Scotland AB24 5UA

ABSTRACT

The seed bank beneath an herb-rich hay-meadow and an adjacent rotationally grazed rough pasture were compared. The seed bank was assessed in samples taken on a 10 m x 10 m grid. Seeds were extracted from the soil, identified and counted. The seed bank of the hay-meadow was significantly different from that of the rough pasture and contained more seeds of a greater number of species. The samples were allocated to five distinct clusters. The seed bank of the rough pasture was very homogenous and all samples were allocated to a single cluster. The implications for restoration or re-establishment of more biodiverse vegetation are considered.

INTRODUCTION

Improvement of agricultural grassland over many decades has led to enclosed herb-rich grassland becoming relatively rare. However, recent countryside policy is leading to extensification e.g. through Environmentally Sensitive Area designation and set-aside. In some schemes, financial incentives are offered for the maintenance or reconstruction of habitats of conservation interest. There is interest in the possibility of using natural seed banks as a means of re-establishing vegetation considered to be of higher conservation value. This is implicit in proposals to change the management regime of vegetation in the expectation this will lead to greater biodiversity of the vegetation. Clearly this technique depends on the existence of a high biodiversity of species which are perceived to be of value occurring in natural seed banks otherwise reliance has to be placed instead on introducing seed from elsewhere.

This paper records the seed bank beneath an herb-rich hay-meadow and an adjacent pasture subject to rotational grazing. This provides information which would be of use in making decisions on the conservation value of specific parcels of land.

MATERIALS AND METHODS

The Highland Folk Park is located north-east of Newtonmore (National Grid reference, NN 719994) on Speyside in north-east Scotland. Aims of the management plan include the improvement of the conservation value of the site. Samples were taken to determine the seed bank of two fields. Field 1 was a long-established, herb-rich hay-meadow with < 25% of plant cover as grasses, mainly *Agrostis capillaris, Holcus lanatus, Festuca rubra, Dactylis glomerata, Anthoxanthum odoratum* and *Arrhenatherum elatius* (names as in Stace (1997)). *Trifolium repens, Ranunculus repens* and *Rumex acetosella* were abundant together with *Bellis perennis, Crepis capillaris, Geranium molle, Leucanthemum vulgare, Plantago lanceolata, Plantago major, Silene latifolia, Sonchus asper, Stellaria graminea* and *Vicia* *sativa* present at lower frequency. Occasional plants of *Achillea millefolium, Anthriscus sylvestris, Campanula rotundifolia, Cirsium vulgare, Galeopsis tetrahit, Matricaria discoidea* and *Veronica polita* were found. This field was bordered by tall rough herb-rich grassland and by scrubby areas and was separated from Field 2 by a farm track. Field 2 had previously been an area of medium height rough grassland dominated by *Agrostis tenuis, Festuca rubra* and *Holcus lanatus*, but with some *Ranunculus repens* and *Trifolium repens*. Field 2 had been rotationally grazed for many years but was ploughed and planted with potatoes in spring 1993.

In spring 1993 soil samples were taken from both fields on a 10m x 10 m grid which led to 36 samples from Field 1 and 30 from Field 2. Each soil sample consisted of five soil cores each 2.7 cm diameter and 5 cm deep positioned randomly within a 1 m × 1 m quadrat located at the grid positions. The five cores were bulked to give a sample of about 200 g soil. Soil samples were bagged and stored at -29 °C until analysis to prevent *in situ* germination.

The defrosted soil was wet sieved on a mechanical vibrator using mesh sizes of 560 µm, 315 µm and 160 µm. The material retained on each sieve was washed into a beaker, excess water removed and saturated calcium chloride added which allowed mineral matter to sink but all organic matter, including seeds, to float. Individual seeds were recovered from the organic material with forceps, identified and counted. Identification used NIAB (1986), Hanf (1983) and a reference collection of seeds made by N. E. Jones in the period 1989-92.

The raw data for each field consists of the number of seeds of each species per sample. Not all species occurred in each sample. The data was analysed using a suite of multivariate methods in MVSP (Kovach, 1998). First, cluster analysis was used to allocate similar samples to groups which could then be mapped. Allocation to groups was based on minimum variance clustering. This technique focuses on the variation within each cluster and minimising this tends to lead to distinct clusters. Detrended correspondence analysis (Hill, 1979) was used to ordinate the data to further examine the similarities between the samples. This technique avoids some of the difficulties of outliers and often gives more interpretable results than regular correspondence analysis. Graphical presentation of the results allows identification of similar samples as ones close together when the results are plotted. In addition the variation in the set of samples can be compared with the distribution of species to infer which species have a large influence on the classification and the distribution of the species along the main axes of variation.

RESULTS

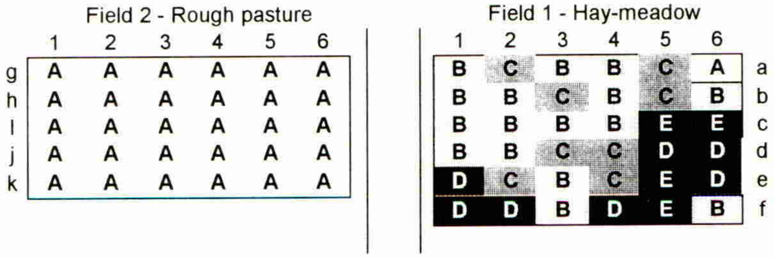
The two fields differed in the size of the seed bank (Table 1). Samples from Field 1 contained an average of five seeds each, equivalent to about 1750 seeds/m^2. In Field 2 the samples contained on average 127 seeds, which is equivalent to 44,400 seeds/m^2. A total of 26 species were found in the seed bank of both fields of which twenty species were found in both. The only species found in Field 2 but not in Field 1 was *Juncus* spp. The six species restricted to Field 1 were all of low occurrence.

Table 1. Number of species found in the seed bank and biodiversity index of seed bank samples from an herb-rich hay-meadow (Field 1) and a rotationally grazed rough pasture, and of the main seed bank sample clusters.

	Number of samples	Number of species		Total seeds per sample		Shannon Index	
		mean	range	mean	range	Mean	range
Field 1	36	12.6	(6 - 17	127.0	(127 - 322)	2.02	(1.38 - 2.47)
Field 2	30	3.3	(0 - 7)	5.1	(0 - 13)	1.04	(0.00 - 1.95)
Cluster A	31	3.4	(0 - 7)	5.4	(0 - 15)	1.06	(0.00 - 1.95)
Cluster B	16	12.7	(8 - 17)	88.2	(41 - 131)	2.08	(1.38 - 2.47)
Cluster C	8	13.1	(10 - 16)	161.5	(100 - 322)	2.03	(1.44 - 2.29)
Cluster D	7	12.6	(11 - 14)	152.6	(85 - 293)	2.02	(1.77 - 2.26)
Cluster E	4	13.0	(10 - 16)	196.3	(141 - 220)	1.95	(1.75 - 2.15)

Frequency of occurrence of species (the proportion of soil samples containing the species) was greater in Field 1, seven species each occurred in > 70% of samples. In contrast, although the common species were the same in both fields, in Field 2 the most frequent species was *Cerastium fontanum* in only 40% of samples. *Stellaria media* was found in 50% of samples in Field 1 and *Vicia sativa* in 22%, but both were absent from Field 2.

The clustering procedure classified each sample on the basis of the species it contained. Five main clusters were recognised (Table 1). Cluster A comprised a set of samples containing 0-7 species. All were samples from Field 2 with one additional sample from Field 1 which had the lowest number of species of all the samples found in Field 1. The samples of Cluster A all contained fewer than 15 seeds, mostly *Juncus* spp. All the other clusters comprised samples from Field 2 and contained at least 8 species and many more seeds (at least 41) than samples from Field 2 (Figure 1).



Field 2 - Rough pasture

	1	2	3	4	5	6
g	A	A	A	A	A	A
h	A	A	A	A	A	A
I	A	A	A	A	A	A
j	A	A	A	A	A	A
k	A	A	A	A	A	A

Field 1 - Hay-meadow

1	2	3	4	5	6	
B	C	B	B	C	A	a
B	B	C	B	C	B	b
B	B	B	B	E	E	c
B	B	C	C	D	D	d
D	C	B	C	E	D	e
D	D	B	D	E	B	f

Figure 1. Distribution of seed bank composition clusters in two fields at the Highland Folk Park, Newtonmore, Scotland.

Table 2. Species characteristic of the five main seed bank sample clusters

Cluster	Species contributing more than 10% of the seeds	Species exclusive to cluster
Cluster A	*Cerastium fontanum*, *Ranunculus repens*.	*Juncus* spp.
Cluster B	*Poa* spp., *Ranunculus repens*.	
Cluster C	*Cerastium fontanum*, *Chenopodium album*.	
Cluster D	*Cerastium fontanum*, *Myosotis arvensis*.	*Geranium molle*, *Silene latifolia*
Cluster E	*Cerastium fontanum*, *Stellaria media*, *Rumex acetosella*.	

Different species comprised a large proportion of the seed bank in the different clusters (Table 2). *Cerastium fontanum* was common except in cluster B. Most clusters had another species contributing over 10% of the seed bank. Rushes were exclusively found in cluster A. Cluster D was the only one which contained *Geranium molle* and *Silene latifolia* and also was the only one not to contain any *Leucanthemum vulgare* or *Galeopsis tetrahit*.

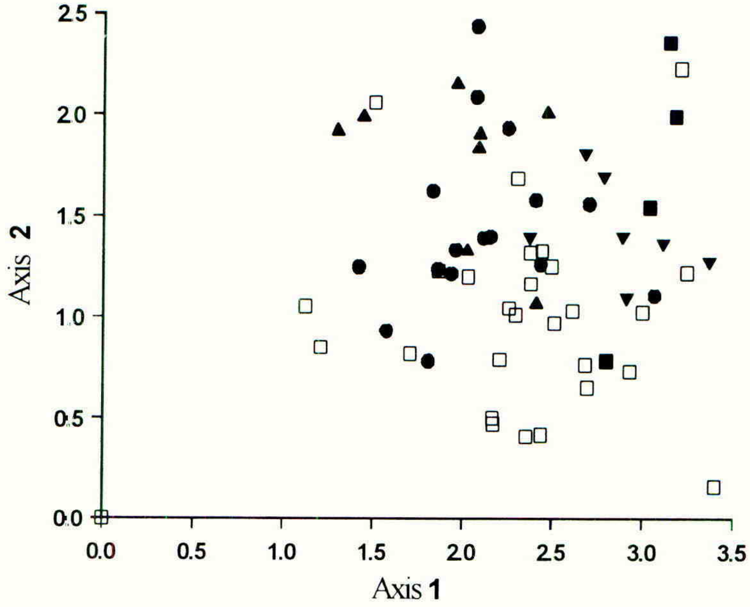


Figure 1. Position of individual samples of clusters A (□), B (●), C (▲), D (▼) and E (■) on axes 1 and 2 of a detrended correspondence analysis.

The detrended correlation analysis largely confirmed the grouping of samples. The axes of the plot reflect the similarity of species composition of samples. Complete turnover of species occurs with 4 units while one unit represents about a 50% similarity of species in samples. Thus axis 1, which accounted for 15% of the total variation, was significantly correlated ($r = 0.31$, $P < 0.01$) with the distribution of clusters. Increasing values of Axis 1 were related to peaks of occurrence of first *Juncus* spp, then *Chenopodium album*, *Ranunculus repens*, *Myosotis arvensis*, *Vicia sativa*, *Rumex acetosella* and lastly, at high values of axis 1, *Cerastium fontanum*. *Stellaria media*, *Silene latifolia* and *Veronica polita* also influenced the position on axis 1. Axis 2 accounted for a further 9% of the variation and was significantly correlated with the total number of seeds ($r = 0.52$, $P < 0.001$) and the number of species ($r = 0.503$, $P < 0.001$) in each sample and therefore, not surprisingly, with the value of the Shannon diversity index ($r = 0.326$, $P < 0.001$).

DISCUSSION

Cultivation has frequently resulted in a decline in the size of the seed bank e.g. Roberts & Feast (1972). In the case of Field 2 continuous grazing over many years has probably been responsible for depleting the seed bank by preventing flowering and the return of seed to the soil. The size of the seed bank estimated in Field 1 is relatively high (Cavers & Benoit, 1989).

The conclusion from these results is that Field 1, the hay-meadow, a moderately species-rich grassland, contains species in the seed bank which could contribute to re-establishment of a species-rich grassland. In the case of Field 2, not only are there far fewer seeds, but the species present are mainly arable weeds not considered of conservation value. Thus, it would be important to establish the conservation potential of any relic seed bank before attempting vegetation re-establishment at any site (van der Valk & Pederson, 1989). However, there are many reports of the lack of correspondence of the seed bank composition with that of the field vegetation (e.g. Major & Pyott, 1966; Roberts, 1981) and the size of the seed bank has been reported to be a poor guide to the number of seedlings established after disturbance (McGowan & Bayfield, 1993). Nevertheless, for an individual species of economic or conservation importance it has been possible to use seed banks to predict future occurrence (Naylor, 1970a, b)

The previous management of a particular site may influence the seed bank and thus the potential biodiversity more than the availability of seeds in adjacent areas. The difference in the size of the seed bank from adjacent grassland field illustrates this. The differences in the seed banks of Field 1 and Field 2 reflect the vegetation, but this is itself a reflection of the different management regimes, one being managed exclusively for hay, the other rotationally grazed. The possibility of transferring soil from an area with high seed bank biodiversity to use as an inoculum in low biodiversity areas could be considered. However donor seed banks rarely produce vegetation identical to that from which they are derived (van der Valk & Pederson, 1989). Vegetation management after the establishment of desirable species is particularly important if they are to survive, set seed and build up a seed bank.

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THE INCIDENCE OF WEEDS IN UK SUGAR BEET CROPS DURING AUTUMN 1998

M A Lainsbury, J G Hilton
Morley Research Centre, Morley, Wymondham, Norfolk, NR18 9DB, UK

A Burn
English Nature, Northminster House, Peterborough, PE1 1UA, UK

ABSTRACT

The study surveyed the level of weeds remaining in the beet crops in Lincolnshire, Cambridgeshire, Norfolk and Suffolk during autumn and early winter. The main weed species present were *Veronica persica, Chenopodium album, Senecio vulgaris* and *Viola arvensis. Stellaria media* in field centres supplanted *Matricaria spp* in field margins. Of these weeds, the most important contributors to the diet of lowland birds are *C. album* and *S. media.* Other important species present in lower numbers were *Poa annua* and *Beta vulgaris*, both important in the diet of many bird species. Exceptionally heavy rain during April resulted in some poor crops and a higher than usual level of *Matricaria* species present in sugar beet. Weed numbers were greatest on the lighter soil types prevalent in Norfolk where leaching of residual herbicides possibly resulted in poor weed control. Heavier soils in other counties are less prone to leaching and the organic peats of Cambridgeshire largely rely on more frequent applications of contact-acting herbicides because the organic matter inactivates residuals.

INTRODUCTION

Crop husbandry has reduced weed numbers in mature crops to negligible levels – true or false? It is true that most cereal crops have relatively low densities and diversity of broad-leaved weeds and, for those fields where control is inadequate, glyphosate is often used as a harvesting aid. The increasing incidence of winter cropping of cereals or oilseed rape means that stubbles are rarely left as areas of readily accessible crop and weed seeds where birds can forage over winter. Because they are harvested late and are often followed by a spring crop, crops such as sugar beet could be considered as surrogate winter stubble in which the birds can forage. Herbicide inputs in conventional beet crops are often high because beet competes poorly with weeds during the early stages of growth. The introduction of GMHT (Genetically-Modified Herbicide Tolerant) crops carries a risk of further reduction in food sources for foraging birds in crops such as beet because of potentially higher levels of weed control.

The objective of this study was to assess the range in density and diversity of weeds in a representative set of beet fields in East Anglia during the autumn to enable an assessment of their potential value as a food source for birds. It could also perhaps establish a benchmark against which the effect of changes in the approach to weed control in this crop could be measured.

MATERIALS AND METHODS

The survey enlisted the help of many consultants who helped locate 10 fields in each of the counties of Lincolnshire, Cambridgeshire, Norfolk and Suffolk. Sites were selected to cover high, low and average weed populations in fields on a range of soil types that were typical of these counties. Once fields were identified, weed numbers in each field were assessed by randomly placing $1m^2$ quadrats at intervals in a triangular pattern across the field. A triangular rather than the traditional "W" pattern was used to ensure detailed assessments of field margins *and* field centres since field margins are an important habitat area and may harbour more weeds than field centres. Data on weeds in field margins are presented separately to those in field centres. Quadrats were randomly placed at intervals of 25 m along the transect course, resulting in a sampling frequency of 14 quadrats per $100m^2$ or 0.14% of the area of the field.

Besides noting the species present, the approximate size and development stage was recorded to assist in assessing the quantity of seed likely to be available from the plants present. Some of the commonest species, e.g. *Chenopodium album* were harvested, dried and the quantity of seed for a given size of plant determined. Farm records of herbicide programmes used on these fields were obtained in order to attempt to co-relate these records with the weed control achieved. A visual assessment was also made of relative weed densities in five beet fields in the immediate vicinity of each field. Notes were made of the hedgerow species and local opinions were sought on whether weed control achieved in 1998 was better, worse or about normal for each field in question.

RESULTS AND DISCUSSION

The survey generated a significant amount of data on weed stages of growth in each of the locations, surrounding vegetation and hedgerows and levels of weed control in neighbouring beet fields. Only those data required to support the overall conclusions are presented in this paper are given in tables 1 – 5. Table 1 shows the frequency of occurrence of weed abundance classes for all fields combined. Tables 2 and 3 show the overall numbers of weeds found at each site for field margins and field centres respectively. Tables 4 and 5 show the frequency with which the commonest species occurred at each site. Many other species were also found occasionally and these data are available in the full report on this work (Lainsbury *et al.*, 1999).

Each of the counties surveyed has a different range of soil types which has a major influence on the range of species encountered. The type of soil will also influence the type of herbicide programme employed in each of the fields and the eventual efficacy. Norfolk has many sandy loams (SL) which have a high weed population and which can be subject to leaching of residual herbicides in wet seasons. Spring 1998 was wet and cold, with localised flooding in many low-lying areas. Suffolk has heavier soils (often sandy clay loams (SCL)) and these soils are much less prone to leaching of herbicides. Peats are common in Cambridgeshire fens and have high organic matter contents, typically above 20%, which absorb residual herbicides and limit their activity.

Table 1. Frequency of weed abundance classes for all fields (see Tables 2 and 3)

Weed density:	0-4/m^2	4-8/m^2	8-12/m^2	12-16/m^2	16-20/m^2	20-24/m^2
Centres:	31	6	1	0	1	1
Margins:	34	3	1	1	1	0

Table 2. Total weeds/m^2 by site number, county and soil type in field margins.

Site No	Norfolk Soil*		Suffolk Soil		Cambs. Soil		Lincs. Soil	
1	SCL	9.2	SCL	0.2	Peat	2.4	Silt	5.1
2	LS	5.9	SCL	1.2	Peat	2.7	Brash	2.0
3	SL	2.9	CL	1.2	Peat	0.9	LS	4.7
4	SL	13.0	SCL	0.3	Peat	0.4	Silt	0.7
5	SL	3.8	SCL	0	Peat	1.8	Peat	1.6
6	FSL	18.5	SL	2.1	SL	0.5	Brash	0.6
7	SL	3.3	SL	3.7	SL	0.1	SL	0.7
8	LS	3.0	LS	2.0	SL	2.3	SL	0.7
9	SL	3.7	SL	3.1	Peat	0.6	LS	1.9
10	FSL	1.1	LS	3.4	Peat	0.5	SL	0.2
	Mean:	6.4		1.72		1.22		1.82
	Max:	18.5		3.7		2.7		5.1
	Min:	1.1		0		0.1		0.2
	Median:	3.75		1.6		0.75		1.15

*SCL, sandy clay loam; LS loamy sand; SL, sandy loam; FSL, flinty sandy loam

Finally, Lincolnshire has a wide variety of soil types including brash soils that have a very high stone content and are prone to drought stress in dry years.

Given the small sample size (10 fields per county), comparison of median values is probably more robust than comparison of means – especially in avoiding bias introduced by individual outliers. However, from the perspective of foraging birds in winter, the 'outliers' of this study, *i.e.* those fields with especially high weed densities, are likely to have great significance. The quantitative relationship between bird feeding requirements and weed density in arable fields is poorly understood (Wilson, 1998). However, based on observations of feeding on winter stubbles, it seems plausible that the weedier fields, which occurred at a much lower frequency than cleaner fields in this study, will have a disproportionately important effect. Table 3 shows that the field centres in Norfolk were weedier than those in the other counties. Table 2 shows a similar picture for the field margins but with greater variation between the other counties. The lighter soils and greater risk of herbicide leaching in Norfolk may explain the apparent poorer weed control there. The peat soils of Cambridgeshire have very high weed seed banks and experience continual flushes of weeds during the early season.

Table 3. Total weeds/m^2 by site number, county and soil type in field centres.

Site No	Norfolk Soil		Suffolk Soil		Cambs. Soil		Lincs. Soil	
1	SCL	22.3	SCL	1.3	Peat	6.0	Silt	3.7
2	LS	6.5	SCL	0.8	Peat	0.2	Brash	2.4
3	SL	9.7	CL	1.6	Peat	0.6	LS	3.5
4	SL	16.4	SCL	0.1	Peat	1.9	Silt	0.4
5	SL	3.1	SCL	0.2	Peat	6.6	Peat	1.1
6	FSL	6.2	SL	1.7	SL	1.7	Brash	4.1
7	SL	2.3	SL	0.3	SL	2.2	SL	0.8
8	LS	0.9	LS	1.4	SL	2.1	SL	1.2
9	SL	4.9	SL	0.8	Peat	0.1	LS	2.0
10	FSL	0.7	LS	2.5	Peat	0.8	SL	0.1
	Mean:	7.3		1.07		2.22		1.93
	Max:	22.3		2.5		6.6		4.1
	Min:	0.7		0.1		0.1		0.1
	Median:	5.55		1.05		1.8		1.6

Table 4. Incidence of common species by county in field margins.

Species (Bayer Code)*	Norfolk	Suffolk	Cambs.	Lincs.	Total	Freq.
ANGAR	2	0	2	1	5	13%
CHEAL	7	0	5	4	16	40%
MALSI	0	0	3	0	3	8%
MATSS	4	3	1	4	12	30%
MERAN	0	0	4	0	4	10%
POAAN	4	3	0	3	10	25%
POLAV	1	1	1	1	4	10%
SENVU	0	5	4	3	12	30%
STEME	4	2	2	1	9	23%
URTUR	0	1	3	2	6	15%
VERPE	3	7	5	3	18	45%
VIOAR	7	1	1	1	10	25%
BETVU	2	0	2	1	5	13%

* For BAYER codes see discussion section

Table 5. Incidence of common species by county in field centres.

Species (Bayer Code)	Norfolk	Suffolk	Cambs.	Lincs.	Total	Freq.
ANGAR	3	2	1	0	6	15%
CHEAL	5	1	4	4	14	35%
MALSI	0	0	1	0	1	3%
MATSS	4	2	1	3	10	25%
MERAN	0	0	1	0	1	3%
POAAN	5	1	1	1	8	20%
POLAV	1	2	1	0	4	10%
SENVU	0	4	4	3	11	28%
STEME	4	2	6	4	16	40%
URTUR	1	1	3	5	10	25%
VERPE	6	6	5	3	20	50%
VIOAR	9	5	6	4	24	60%
BETVU	2	1	1	1	5	13%

Beet crops on these soils tend to receive a high number of contact sprays to remove each flush as it emerges before the canopy closes. However, further analysis of the patterns of herbicide use on individual fields will help in interpreting differences in weed levels.

The most commonly occurring species in the field margins was *Veronica persica* (VERPE), found in 45% of fields in all counties followed by *Chenopodium album* (CHEAL) in 40% of field margins (Table 4). Some of these plants were the result of fresh germination underneath the crop canopy but even these set seed, albeit at lower numbers than those above the crop canopy. *Matricaria spp* (MATSS) and *Senecio vulgaris* (SENVU) were found in 30% of fields but the high level of MATSS, with surface-germinating seed and a shallow root system, was indicative of the very wet season. Table 5 shows that most of the same species are also present in the field centres although *Stellaria media* (STEME) replaces *Poa annua* (POAAN) in the top six species.

As a member of the *Gramineae*, POAAN is an important component of the diet of declining farmland species. CHEAL is also important in the diet of declining species (Wilson, 1998). Weed seeds from the families Scrophulariaceae (*e.g.* speedwells) and Violaceae (*e.g.* pansies) are found in the diet of many species, but are considered important to relatively few. The third most abundant mid-field species was STEME which is considered important to several declining species such as grey partridge, tree sparrow, linnet, bullfinch and reed bunting. It also contributes to the diet of many other farmland birds (Wilson, 1998).

One declining farmland species that occurs widely in beet fields, particularly in the early spring as the beet is establishing, is the skylark. This species favours field centres over field margins and weeds that Wilson *et al.* (1996) found to be important in its diet were weed beet (BETVU) and *Polygonum aviculare* (POLAV). Studies linked to this project found that the BETVU plants produced 500 – 5000 seeds per plant with average seed weight of approx. 0.03gm. Hanff (1983)gives similar figures for this species. POLAV plants have fewer seed (125 – 200 per plant) but at 3 mm long, they are favoured by many bird species, including skylarks and linnets. Of the other weeds commonly found in field margins and centres, *Urtica urens* (URTUR) is an important food of bullfinches and dunnocks. *Mecurialis annua* (MERAN) is favoured by bullfinches while *Anagallis arvensis* (ANGAR) and *Malva sylvestris* (MALSI) occur in the diet of some birds but do not form an important component of any. Hanff (1983) lists CHEAL as capable of producing 3- 20,000 seeds per plant, each 0.7 – 1.5 mm in size and representing a considerable food source to seed eating birds. SENVU is restricted to 2-3000 seeds per plant but MATSS can produce up to 200,000 seeds per plant. Seeds produced by POAAN are not as plentiful but are large (up to 4 mm in length), and are a potentially valuable resource.

The data presented in Table 1 show that 85% of the fields surveyed had 4 weeds/m^2 or less in their margins and 78% had less than 4/m^2 in their centres and only 2.5% had more than 20/m^2 and 5% had more than 16/m^2. These fields are likely to have the greatest value as a food source for birds. The introduction of GMHT beet will simplify weed control in beet and is therefore likely to improve the ability of growers to achieve good weed control under a range of soil and weather conditions. It will also improve control of difficult weeds closely related to sugar beet such as CHEAL and BETVU and so is likely to reduce the number of fields with high weed densities in the autumn. However, since the total herbicides currently under development have no residual herbicide activity, they will allow the germination of weeds under the crop canopy. Such weeds will set seed, albeit in smaller numbers than plants at field margins. Thus, the introduction of GMHT beet is likely to reduce the incidence of very weedy fields but may allow higher weed densities under crop canopies, spreading the weeds over a wider area but reducing their impact on beet yields.

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Auditing the arable flora – problems and some possible solutions

P Wilson
Wessex Environmental Associates, 4 Prospect Place, Grove Lane, Redlynch, Salisbury SP5 2NT, UK

S Kay
The Northmoor Trust, Little Wittenham, Abingdon, Oxfordshire, OX14 4RA

J Phillips, L Lock
RSPB, Keble House, Southernhay Gardens, Exeter, Devon, EX1 1NT, UK

ABSTRACT

Many arable plant species have become extremely rare in Britain during the second half of the 20th century, and their conservation has become a priority. One obstacle to the effective implementation of conservation programmes is an inadequate knowledge of species status and distribution, and of sites of conservation importance. There are many problems inherent in the survey of arable plants, and several methods have been tested. A suitable method for large-scale survey will probably involve collation of existing information and targeting of survey effort. Systematic survey may only be possible with the help of volunteer labour.

INTRODUCTION

As a result of the rapid and revolutionary changes in arable farming practice during the second half of the 20th century, many species of plant formerly associated with arable land have become much rarer in Britain and in the rest of Europe (Holzner, 1977; Wilson, 1990). These changes have affected both the number and size of populations. Many species are now included on the lists of Species of Conservation Concern in the UK Biodiversity Action Plan (BAP) (Anon, 1998; Wilson 1999), and the British government are committed to their conservation.

An obstacle to the effective conservation of arable plants and plant communities has been an inadequate understanding of their distribution and lack of knowledge about the location of the most important sites. Such information is essential for the evaluation of conservation priorities and for subsequent targeting of conservation effort.

Segetal plants are extremely difficult to survey. Although in general they tend to be highly site-faithful because of their persistent seed-banks, their detectability varies greatly from year to year depending on crop type (Wilson, 1990), type and efficiency of herbicide and nitrogen application, weather conditions and several other factors. Species may therefore not be recorded when in fact they may still be abundant in the seed-bank. Traditional methods of botanical record gathering do not favour arable habitats - a largely volunteer workforce is reluctant to search vast areas of apparantly uniform and botanically impoverished habitat for little reward; biodiversity hotspots cannot easily be located as they can in other semi-natural habitats. Access to much arable land is difficult to obtain, and what little recording there is may often be limited to gateways and areas adjacent to footpaths. Surveys carried out by the BSBI and NCC during 1986 and 1987 gathered much valuable information but were constrained by these factors (Smith, 1988).

In addition to problems in gathering information, there are also difficulties in the interpretation of data gathered from one point in time when it is likely that many populations are in long-term decline. The standard tools used in assessing botanical conservation priorities are the Atlas of the British Flora (Perring & Walters, 1987, review in progress), the Vascular Plants Red Data Book (Perring & Farrell, 1983; Wigginton, 1999) and Scarce Plants in Britain (Stewart et al, 1994). For the reasons outlined above, the information on which these are based may be incomplete for arable habitats. Records may also have been gathered over a period of sufficient length to obscure any change in status. In Stewart et al (1994) for example, the data collection period was between 1970 and 1992, a period that included what may have been the most rapid declines of several arable plant species. Inclusion of all data collected within that period on a single map would have resulted in a considerable overestimate of distribution. Maps for seven species showing records before and after 1980 were presented, demonstrating the decline in number of sites during this period. Abundance also may be overestimated when presence or absence in 10km squares is the only measure recorded. A single plant of one species in a 10km square would be recorded in the same way as numerous populations of another species containing large numbers of plants. Small relic populations are typical of species such as arable plants which are in the process of rapid decline. There has also been a tendency to include casual and introduced populations of some species in the datasets used for assessing status.

In summary, underestimates of arable plant distribution may occur as a result of poor survey coverage and temporary non-appearance of plants due to adverse conditions in the survey year Overestimates may occur as a result of collation of data over an excessively long time period, the of presence/absence in grid squares as the only measure of distribution and the inclusion of casual and introduced populations in datasets. Methods of survey and data interpretation are therefore required which attempt to overcome these obstacles.

METHODS

Some approaches to the assessment of the botanical diversity of arable farmland are illustrated using examples from the South-West of England, Wiltshire and Oxfordshire. All of these exercises had some aims in common: to identify important sites for arable plants, to raise the profile of arable plant conservation and to aid the targeting of farmland conservation schemes.

A botanical audit of arable farmland in South West England

This audit consisted of a desk study which collated known information on 40 species of plant associated with cultivated land, field margins and disturbed grassland in SW England (Cornwall and Isles of Scilly, Devon, Somerset, Dorset, Wiltshire, former county of Avon and Gloucestershire) (Lock & Wilson, 1996). The majority of the data was contributed by BSBI recorders with some additional information from county Wildlife Trusts, Biological Records Centres and others. From this desk study, important areas for arable plants were identified and links were made with other farmland taxa to identify target areas of high biodiversity for farmland initiatives including Countryside Stewardship. These areas included the South

Wessex Downs, mid Somerset, Portland-Purbeck, south Devon, the Cornwall coast and the Isles of Scilly.

The report was produced in parallel with the SW Regional Biodiversity Initiative and a summary of the information gathered was fed directly into the regional documents (Cordrey, 1996 & 1997). As a result, both audit and action plans for arable land were included in these, and the important areas identified through the arable plant auditing exercise were recognised as farmland `hotspots' and given priority for conservation action within the region.

At a time when there was little recognition of the importance of arable habitats and the species associated with them, the audit was very important in raising the profile of the species and issues and in setting them alongside the more widely accepted conservation priorities in the regional context. Given the regional initiative's multi-partnership support, including endorsements from English Nature, Environment Agency, MAFF, etc, this has helped draw many organisations into the debate about arable conservation.

Arable plant auditing in Wiltshire

Wiltshire has long been recognised as an important county for arable plants, and the chalklands of the South Wessex Downs were identified as an area of importance for farmland biodiversity by Lock & Wilson (1996). The county is of particular importance for the characteristic calcareous weed communities and it may also hold the best sites for *Adonis annua* and *Galeopsis angustifolia* in the UK (Phillips, 1999). It was hoped that the key audience for the audit would be FRCA Countryside Stewardship officers, FWAG officers and ESA project officers, all of whom are involved with farmland conservation in Wiltshire. Knowledge of site location would allow their management to be integrated into any future CS and ESA applications and FWAG Whole Farm Plans.

The audit concentrated on 24 key species. All nationally rare and scarce arable plant species (Wigginton, 1999; Stewart, Pearman & Preston 1994) and all Priority species and Species of Conservation Concern listed in the UK BAP were selected. Other species which have shown worrying declines in range in recent years, or have nationally important populations within the region were also included.

Data were gathered from Wiltshire Biological Records Centre, Wiltshire Wildlife Trust, BSBI (Botanical Society of the British Isles) recorders, Wiltshire Botanical Society, local botanists, English Nature and the RSPB Wessex Stone Curlew Project. Much of this data had previously been compiled by Lock & Wilson (1996). Only records from 1990 onwards were included, although some other sites with pre-1990 records were included if they were thought still to be extant but had not been surveyed in recent years. Site name and description, grid reference, date of last survey, owner, agri-environment schemes in place, other notable species present, any other information and a site map were compiled for each of the sites.

The most obvious conclusion from the audit was the lack of recent surveys for the sites highlighted, with few sites having been surveyed within the last 5 years. This was addressed during 1999 with 40 sites being re-surveyed by the Wiltshire Botanical Society. This survey concentrated on the sites included in the audit, but surveyors have been asked to search adjacent fields also. Full results of this survey are not yet available, but important new sites not highlighted in the audit have already been discovered.

Systematic survey in Oxfordshire.

Two areas of Oxfordshire, the Midvale Ridge Natural Area and the Chilterns Area of Outstanding Natural Beauty were targeted by The Northmoor Trust for detailed systematic recording of arable fields.

At the start of the project a list was compiled of 51 arable flower species which were thought to be rare or declining both nationally and within Oxfordshire (Hunt, 1996). All arable fields were surveyed within nine full parishes and four part-parishes in the Midvale Ridge from 1996 to 1998 (290 fields)(Hunt, 1996; Sutcliffe, 1997; Kay & Gregory, 1998) and all the arable fields within six full parishes in the Chilterns in 1999 (149 fields). The margin of each arable field was walked and any species from the target list was recorded with a measure of abundance on a 1-5 scale. A note was also made of the soil type and the crop type in the survey year of each field.

Table 1. Target arable flower species and the percentage of fields in which they were recorded during the systematic surveys of arable plants in the Midvale Ridge and the Chilterns from 1996 to 1999. The three most common species recorded from each area are in bold type.

Scientific name	National Status	% of fields in Oxford Heights	% of fields in Chilterns
Species of high conservation concern			
Anisantha diandra	-	4%	1%
Anthemis arvensis	?	0.3%	-
Apera interrupta	Nationally scarce	5%	-
Fumaria densiflora	Nationally scarce	2%	15%
Fumaria vaillantii	Nationally scarce	-	0.7%
Iberis amara	Nationally scarce	-	0.7%
Misopates orontium	-	-	0.7%
Scandix pecten-veneris	Nationally scarce	2%	5%
Species of lower conservation concern			
Anchusa arvensis		**22%**	0.7%
Chrysanthemum segetum		6%	-
Euphorbia exigua		5%	**28%**
Geranium pusillum		**34%**	9%
Kickxia elatine		3%	**18%**
Kickxia spuria		4%	14%
Legousia hybrida		4%	9%
Lithospermum arvense		1%	0.7%
Myosurus minimus		1%	-
Papaver argemone		**16%**	12%
Papaver hybridum		1%	0.7%
Petroselinum segetum		3%	3%
Polygonum rurivagum		0.7%	-
Ranunculus arvensis		0.3%	-
Sherardia arvensis		3%	**27%**
Spergula arvensis		4%	4%

Twenty-seven of the target species were not refound. However, 24 target species were recorded although some were very infrequent (Table 1). *Anthemis arvensis* and *Misopates orontium* were each recorded from only one of the total of 439 fields. Some species were however recorded more frequently than expected. *Fumaria densiflora* was recorded from 15% of fields surveyed in the Chilterns. *Scandix pecten-veneris* was also present in both of the study areas, locally occurring in abundance.

The Northmoor Trust is now in an ideal position to have a role in the conservation of Oxfordshire's arable flora. Farmers with rare arable plants on their land have been invited to consider the Countryside Stewardship Scheme, or to incorporate arable plant conservation into their Whole Farm Plans. The next step for the project is to find out whether rare arable flowers are benefiting from these conservation initiatives, or whether they are continuing to decline.

CONCLUSIONS

All three methods could have a role in the assessment of arable botanical diversity on a larger scale. In isolation, all have shortcomings, and a synthesis of all three may be a useful starting point for a national survey strategy. Whatever method may be adopted, it will be essential for the results to be subject to careful interpretation and evaluation.

Records collated by a desk survey will provide a valuable basis for targeting survey work and would be an essential first stage in any wider-ranging programme. The results of such a survey may also provide a partial base-line dataset from which assessments of change can be made. Such an exercise however will not locate all potential nuclei of diversity, and may suggest that such nuclei exist when all species of conservation value may have disappeared many years previously.

Systematic surveys such as those carried out in Oxfordshire provide the most comprehensive information. Systematic survey can also give information about the crop types and soil types most favourable to rare arable plants. It requires close liaison with landowners and allows the establishment of a working relationship between conservationists and farmers which is a considerable advantage when negotiating conservation management. The major disadvantage is that systematic surveys are very labour intensive. One surveyor took three 12-week field seasons to survey 290 fields, covering only approximately 50% of the target survey area. Even if sufficient competent surveyors could be found, it is highly unlikely that funding would be available. A further disadvantage with the Oxfordshire surveys is that they were only carried out in a single year at each site. Repeated surveys are necessary to detect the full flora of an arable field as the presence of plants may be strongly influenced by the efficiency of herbicide applications, crop competitivity, the time of crop drilling and weather conditions. Repeated survey would further increase costs.

Careful targeting of surveys may be the most effective use of resources. Areas for search can be selected partly on the basis of previously gathered records and historically known areas of high botanical diversity. Other factors can be included to broaden the area of search to include previously unlocated sites. One of the chief factors may be the length of time in arable cultivation. Fields that were in cultivation in the mid-19th century are more likely to have uncommon species than fields more recently converted from permanent grassland (Wilson, 1990). Soil type has been an important influence on the survival of rich floras. Sandy and chalk soils are now more likely to support rich arable plant communities as a result of the relative effects of management intensification on different soils (Holzner, 1977; Kay & Gregory, 1998). Clay soils can however also have uncommon species, and farms that are known to have been managed unintensively should also be targeted.

Such a targeted and focused approach may be the best way to deliver favourable management to important sites quickly. With agri-environmental grant schemes being currently so underfunded, identifying and targeting 'hotspots' may be one of the best ways to ensure the conservation of arable plants at present. Large-scale botanical surveys in Britain have however traditionally relied on the work of the large number of highly skilled and experienced volunteer botanists, coordinated by the BSBI (Botanical Society of the British Isles). Surveys of rare arable plants were carried out by the BSBI in the 1970s (Chancellor, 1977) and the 1980s (Smith, 1988). If this workforce could be mobilised, then a comprehensive national survey carried out over several years could be possible.

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Pre- and post-dispersal weed seed predation and its implications to agriculture

C J Swanton, J T Griffiths, H E Cromar, and B D Booth
Dept of Plant Agriculture, University of Guelph, Guelph, Ontario, N1G 2W1, Canada

ABSTRACT

We investigated pre- and post-dispersal seed predation to determine whether they would reduce weed seed populations and whether the intensity of predation could be manipulated by altering tillage or cultural practices. Both pre- and post-dispersal predation significantly decreased weed seed density. Pre-dispersal predation was variable and reduced seed production of *Amaranthus retroflexus* and *A. powellii* by 3 to 40% in 1998. Post-dispersal predation reduced seed density of *Echinochloa crus-galli* and *Chenopodium album* by 3% per day. The combination of pre- and post-dispersal seed predation may therefore be a significant broad-spectrum form of biological weed control. Furthermore, these high levels of predation may account for some of the patchiness observed in the distribution of annual weeds. This has implications for precision agriculture which focuses primarily on soil characteristics to explain weed distribution.

INTRODUCTION

Pre- and post-dispersal predation is known to limit the abundance and/or distribution of seeds in many natural habitats (Crawley, 1992). Predation intensity varies spatially and temporally and is dependent on a variety of factors including "plant density, seed crop size, within-season phenology, pollination rate, spatial location, weather conditions, predator density, and availability of alternative hosts" (Crawley, 1992).

Seed predation may also reduce weed seed populations in agricultural systems; however, this is largely unexplored. The goal of this research was to examine the intensity of pre- and post-dispersal seed predation of several weed species. We wanted to know whether predation intensity is strong enough to influence weed population dynamics. In addition, we wanted to establish whether predation could be manipulated using tillage or cultural practices.

MATERIALS AND METHODS

Pre-dispersal predation

To examine the role of pre-dispersal seed predation, pre-germinated seeds of *Amaranthus retroflexus* and *A. powellii* (in mixture) were planted in corn, allowed to grow, and then predation levels measure. These two species (redroot and green pigweed, respectively) are found as a complex in nature and have similar seed and seedling morphologies.

Prior to planting the corn, glyphosate (N-(phosphonomethyl)glycine) was applied to control existing weeds. Corn was planted in row widths of 37.5cm and 75cm (traditional practice) with planting densities of 75,000 (recommended) and 100,000 plants/ha. A pre-emergence herbicide (metolachlor/dicamba) was also applied eight days after planting. Corn was over-seeded and then hand thinned to appropriate densities. An additional treatment of 75cm row width at 75,000 plants/ha density was treated with glufosinate (at 400 gai/ha) applied at the 7-8 leaf stage.

Amaranthus seeds were planted in a "W" pattern within each 9x9m plot and later thinned to one individual in each of the 15 planting locations. Two controls, insecticidal (imidacloprid) and bagging (of no-see'm mesh), were used to determine full seed count on unpredated individuals. In each plot there were 5 plants for each treatment (predated, bagged, insecticide) and there were 4 blocks per treatment. Weed plants were monitored to ensure that seed heads were collected after maturation, but before dispersal. The terminal inflorescence of each pigweed plant (5 subsamples from each treatment) was measured, collected, and dried, and seeds visually examined and counted.

Post-dispersal predation

In an earlier study (1995-1997) we examined post-dispersal predation on *Echinochloa crus-galli* (barnyardgrass) and *Chenopodium album* (common lambsquarter) (Cromar *et al.*, 1999). To do this, petri dishes (8.8cm diameter) containing seed were placed in the field under various treatments. Seeds were placed in the dishes, covered with soil and dishes were buried flush to the soil surface. They were then covered with surrounding residue to mimic field conditions. Dishes were placed out either in the fall (after harvest) of 1995 or 1996 (for ca. 2 months), or the spring (after thaw) of 1996 or 1997 (for ca. 4-6 weeks) depending on weather conditions. All dishes were protected with a roof to deter seed removal by rain. To differentiate vertebrate from invertebrate predators one-third of these structures were covered with a mesh (7x7mm) to exclude vertebrates. As a control, one third were covered with mesh (1.5x1.5mm) to exclude all predators. There were six replicates of each treatment. Once removed from the field, seeds were extracted and counted.

This general set-up was used to look at post-dispersal predation in two ways. First, to look at the effect of tillage on predation rate, dishes were set out in corn following either fall moldboard plow, fall chisel plow, or no-till. Second, to look at the effect of the crop cover on predation, dishes were set out at a separate site under long-term no-till of corn, soybean and wheat residue. To identify predators, Sherman live traps and pit-fall traps were placed out in each treatment to sample mammals and invertebrates.

RESULTS

Pre-dispersal predation

The larvae of a Lepidopteran micro-moth (*Coleophora lineapuvella* (Chambers)) was identified as the major pre-dispersal seed predator. These larvae are phyto-monophagus, feeding exclusively on *Amaranthus*. The evidence of predation was very specific to this one organism and it could be seen as either a single entrance hole, an entrance and exit hole, or partial loss of the seed coat.

Pre-dispersal predation rates of *Amaranthus* were highest with low planting density, whereas in high density plantings predation rates were much lower (5%) (Table 1).

Table 1. Weed characteristics and percent of *Amaranthus* spp. seed lost to pre-dispersal predation when grown in corn planted at two row widths and at two densities.

Row Width cm	Density no/ha	Predation %
37.5	100,000	3 c
37.5	75,000	40 a
75	100,000	3 bc
75	75,000	22 b

Means followed by the same letter are not significantly different according to Tukey's test ($p=0.05$)

Data from the insecticide sprayed controls were used to calculate the predicted seed production based on infloresence length in the absence of all insect predators. Total seed production per inflorescence of these plants was regressed against inflorescence length ($r^2=0.506$; $p<0.05$). The mean terminal inflorescence length was 5.0cm. From this we were able to predict the number of seeds produced per average infloresence. This was compared to the total seed production (predated + unpredated seeds) of predated inflorescence. For the averaged length infloresence ($x=5.0$cm) total seed production of predated inflorescence was 11% lower than nonpredated controls.

Post-dispersal predation

A variety of post-dispersal seed predators were identified. Small populations of field mice (*Peromyscus leucopus* and/or *P. maniculatus*) were present at both sites; however, they were not numerous enough to analyze statistically. Overall, 26 families of invertebrates were collected. Carabid beetles were the most abundant. Sow bugs (Isopoda), millipedes (Myriapoda) and carabid beetles (Insecta: Coleoptera) comprised over 70% of the ground-dwelling invertebrates (Table 2). There were no consistent differences between treatments in invertebrate richness or abundance.

Seed predation was high in both experiments (tillage and crop cover), and there was no difference in predation rate between the two species. The mean percent seed loss for both species was between 25% and 31% in both experiments. Predation intensity, however, did differ among tillage treatments and crop cover treatments. It was highest under no-till and moldboard plow, and highest under corn residue (Table 3).

To estimate the intensity of post-dispersal seed predation, Cromar *et al.*, (1999) calculated the mean daily predation of barnyard grass seed in the fall under no-till. Seed predation was 43% over an approximate 15 day period (of unfrozen ground). Therefore, the mean daily predation rate during thus period was was 2.9%.

Table 2. Percent of three dominant ground dwelling invertebrates (% of treatment total) and total invertebrate abundance found in the tillage and crop cover experiments. Percents represent means from five traps in each of two treatment replicates over three sample periods.

	Tillage Treatment			Crop Cover Treatment		
	No-Till	Chisel	Moldboard	Corn	Soybean	Wheat
Class	%	%	%	%	%	%
Crustacea - isopods	16	<1	3	26	34	24
Diplopoda - millipedes	23	10	11	25	13	29
Insecta - Coleoptera - Carabidae	41	61	60	25	35	24
Total number of individuals caught	982	1004	860	1334	1105	1150

Table 3. Percent seed predation in tillage and crop cover experiments. Percents are based on means of spring and fall sampling periods from 1995 to 1997.

Tillage Treatment			Crop Cover Treatment		
No-Till	Chisel	Moldboard	Corn	Soybean	Wheat
%	%	%	%	%	%
32 a	24 b	32 a	31 a	24 b	21 b

Means (within each study) followed by the same letter are not significant according to Tukey's multiple comparison test (p=0.07).

DISCUSSION

There is strong evidence that weed populations are at least partly controlled by seed predation. Weed seeds were consumed in large numbers both before and after dispersal. In addition, predation intensity could be manipulated using tillage practices or altering crop residue type. Pre- and post-dispersal predation, however, must be considered as separate modes of weed control because predation intensity will vary both within and between species. Therefore, management schemes would have to deal with them separately.

Direct pre-dispersal seed predation of *Amaranthus* spp. by *C. lineapuvella* accounted for a 26% reduction in seed number (mean of all treatments). Also, there is evidence that a decrease in seed production occurred due to other organisms: total seed production was 11%

higher when all insect feeding was eliminated (in imicloprid-treated plants). Other functional groups of phytophagus insects may have reduced the over-all fitness of pigweed thus indirectly reducing its ability to produce seeds. This assumes, of course, that imicloprid has no other effect on the pigweed. Thus, for *Amaranths* spp. seed production was reduced by a total of 37% before dispersal by the direct and indirect effects of phytophagus insects.

Post-dispersal predation was also high. In barnyard grass, the mean seed rain from plants emerging after the 4th leaf stage of corn was 2000 seeds/m^2 (Bonsic & Swanton, 1997). Post-dispersal predation of barnyardgrass in no-till was approximately 2.9% per day in the fall. If this level of seed predation occurs over a 60 day period before snowfall (mean time between harvest and snowfall), then seed density could be reduced up to 82% to approximately 360 seeds/m^2. This estimate is likely conservative because it does not include pre-dispersal predation, nor does it consider post-dispersal predation at other times of the year (Cromar *et al.*, 1999).

Both pre-and post-dispersal seed predation may prove to have important implications to weed management and to agriculture in general. We would like to address two of these. First, this research suggests that losses due to seed predators may have the potential to influence weed population dynamics. Second, this research has implications to the practice of precision agriculture. These points will be discussed below.

Implications to Agriculture

Typically, seed predation is rarely considered when modeling weed demographics, and when it is, we believe that it is generally underestimated. In weed seed return experiments, pre-dispersal predation is typically not taken into account at all. The number of seeds produced per plant is counted, and seed returns calculated based on this. Our research, however, shows that this will overestimate seed returns. For example, rather than 1000 seeds/pigweed plant being returned to the soil (as predicted by Knezevic *et al.*, 1994), this research suggests that 630 to 760 seeds/plant will be returned if pre-dispersal seed predation is included (Griffiths, 1999). Likewise, post-dispersal predation of barnyardgrass may reduce seed input from 2000 to 360 seeds/m^2 (Cromar *et al.*, 1999). Thus when modeling seed dynamics, both types of seed predation should be included when predicting weed population dynamics.

Precision agriculture is a crop management system that uses both spatial and temporal information to manage within-field variability. Information on soil characteristics, nutrient status, biophysical characteristics etc. are gathered and related to crop yield and weed distribution. Then, inputs such as fertilizers and chemicals can be reduced by applying them only on a 'where necessary' basis (Cook & Bramley, 1998). It is an appealing idea. It begs the question, however, of whether the observed variation (or patchiness) observed in weed distribution is actually controlled by these 'bottom-up' processes (Nowak, 1998). To date, most of the work in precision agriculture has focused on soil and biophysical characteristics. While soil characteristic may determine where weeds are *able* to grow, other factors such as predation will likely determine where they *do* grow. Our research suggests that the distribution of annual weeds is at least partly controlled by seed predation and therefore, seed predator distribution is likely central to the understanding of why weeds occur in patches. These are issues not currently addressed in precision agriculture.

Conclusions

We observed high levels of weed seed predation both before and after they had dispersed. A host-specific predator characterized pre-dispersal predation, while a variety of generalist feeders were observed in post-dispersal predation. This is a typical difference between pre- and post-dispersal seed predators. The combination of pre- and post-dispersal seed predation may be a significant broad-spectrum form of biological weed control. Management strategies that maximize vertebrate and invertebrate seed predators should be encouraged.

Further work on weed seed predation could take several strategies. First, predation surveys of a variety of weed species (before and after dispersal) could be done to determine how intensity varies between and within species and at which time intensity is strongest. Second, predation under various tillage and cultural practices could be examined to determine ways to maximize weed seed loss. Finally, longer-term studies could be done to determine the extent to which predation can limit weed density and distribution.

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Tolerance of Transgenic Soybean (*Glycine max*) to Heat Stress

J M Gertz, Jr., W K Vencill, and N S Hill

Department of Crop and Soil Sciences, University of Georgia, Athens, Georgia, 30602, USA

ABSTRACT

Greenhouse studies were conducted to compare agronomic and physiological characteristics of selected herbicide-resistant and conventional soybean (*Glycine max*) varieties. Growth chamber studies were initiated to examine the effects of heat stress of soybean in a sterile environment. Twelve soybean varieties (six glyphosate-resistant, one glufosinate-resistant, one sulfonylurea-tolerant, and four conventional varieties) were examined in three temperature regimes (25/20°C, 35/30°C, 45/30°C). Overall, soybean growth was most vigorous at 35/30°C and poorest at 45/30°C. Glyphosate-resistant soybeans tended to be more susceptible to heat stress than glufosinate-resistant and conventional soybean varieties. The glyphosate-resistant soybean varieties tended to be shorter and lower in chlorophyll content and fresh weight than non-glyphosate-resistant soybean varieties. Base stem splitting between V1 and V2 that had been reported from field observations was observed at the 45/30C regime. Glyphosate-resistant soybean varieties exhibited a higher percentage (90-100%) stem splitting than glufosinate-resistant (50%) or conventional soybean varieties (45-70%). To better understand the stem splitting effect, an acid-detergent fiber (ADF) analysis was conducted to determine lignin content of stems. At 25/20°C, glyphosate-resistant soybeans had elevated lignin content (12-13% w/w). At 45/30°C, the lignin content of conventional soybeans equaled that of the glyphosate-resistant soybean varieties. A significant correlation between lignin content at 25/20°C and stem splitting at 45/30°C was observed.

INTRODUCTION

Crops can be made resistant to herbicides by either breeding for resistance through selection, or by using biotechnology (Dyer *et al.* 1993). Increasing knowledge of herbicide mechanism of action combined with rapid progress in molecular genetics have lead to the identification, isolation, and modification of numerous soybean genes encoding for the target proteins of herbicides (Tsaftaris, 1996). Currently, glyphosate-resistant, glufosinate-resistant, and sulfonylurea tolerant soybeans are on the market in the United States.

Glyphosate , a non-selective herbicide that inhibits the synthesis of aromatic amino acids via inhibition of 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), was the first herbicide for which soybean resistance was developed (Delannat *et al.*, 1995). The resistance mechanism is based on expression of an altered form of EPSPS (CP4 EPSPS) expressing resistance to glyphosate at the site of action (Padgette *et al.*,1995). Research to develop glufosinate-resistant technology in crops has been ongoing since 1987. Resistance to glufosinate-ammonium is based on metabolic detoxification (AgrEvo Company, 1996).

Variety performance, quality, and yield are of primary concern to growers. In 2 of the last 3 years, glyphosate-resistant soybeans have been marketed in Georgia. In that time, some growers have complained about the performance of glyphosate-resistant soybean under conditions of heat and drought stress. To date, herbicide-resistant varieties have not been compared to each other and conventional varieties to evaluate variety performance under conditions of heat stress more commonly found in the Southern United States. A growth chamber study was also conducted to compare variety performance under heat stress.

MATERIALS AND METHODS

Seeds of all varieties were planted in 0.47-l cups with Cecil sandy loam soil and germinated in a greenhouse. Soybeans were thinned in each cup resulting in 2 plant per cup. Five replications of each variety were placed in growth chambers maintained at 25/20°C with 16-hour photoperiod (900 M m^{-2} s^{-1} irradiation) or 35/30°C with 16-hour photoperiod (900 :M m^{-2} s^{-1} irradiation). Cups in both growth chambers were kept well watered. Replications were laid out in both growth chambers in a complete randomized block design.

After 32 days in the growth chamber chlorophyll content, height, and shoot weight readings were taken. Chlorophyll content was taken with a Minolta SPAD 502 chlorophyll meter, by 12 samples averaged per cup from six subsamples taken from the six leaves of the two most recently fully developed trifoliolates. Height was the result of the height from the soil to the terminal node of the plant with the two plants measured and averaged. Shoot weight was the result of the average weight of the two shoots per cup.

The experiment was repeated twice. It was then again repeated two more times at two different temperature regimes. In these, two repeats the same varieties, cups, and number of replicates per variety were used. However, prior to the seeds being planted they were sterilized in sodium hypochlorite. The seeds were then planted into a sterilized Cecil sandy loam soil and allowed to germinate in a growth chamber set at 25/20°C that had been previously sterilized with sodium hypochlorite. Five repetitions of each variety stayed in the 25/20°C-growth chamber and the other five repetitions were moved to a sterilized 45/30°C growth chamber at 16 hour photoperiod (900 :M m^{-2} s^{-1} irradiation). As in the previous experiment, replications were laid out in both growth chambers in a complete randomized block design. The plants in the 45/30°C growth chamber were placed in a pan that had previously been sterilized with sodium hypochlorite.

At the V1 and V2 stage of development, a stem spitting reading was made. After 32 days in the growth chamber chlorophyll content, height, and shoot weight readings were taken. The plants were then dried at 38°C to 10% moisture content for lignin analysis. After the tissue had dried, the stem tissue for each variety and rep from both the 25/20°C and 45/30°C temperature regimes was isolated so that only the lignin content of the stem tissue was investigated. Lignin concentrations of stem tissue were determined gravimmetrically using techniques described by Goering & Van Soest (1970). The experiment was a complete randomized block design with five replicates and was repeated twice. Data was analyzed using analysis of variance and means were separated using Fisher's Protected LSD test at p = 0.05.

RESULTS AND DISCUSSION

Plants were tallest at 35/30°C and shortest at 45/30°C (Table 1). Plants had the greatest weight at 35/30°C and the least weight at 45/30°C. Plants had a higher percent stem lignin content at 45/30C than at 25/20C (Table 2). Stem splitting was observed at 45/30°C (Table 2) but was completely absent at 25/20°C and 35/30°C (data not shown).

Regardless of temperature, orthogonal contrasts showed that the conventional Hartz variety was taller than the Hartz glyphosate-resistant varieties. Regardless of temperature, orthogonal contrasts showed that the conventional Asgrow variety was taller than the Asgrow glyphosate-resistant varieties. The sulfonylurea tolerant variety was the tallest of the varieties at 25/20°C, but not at 35/30°C or 45/30°C. There was no difference in height between the conventional 'Hutcheson' variety and the glufosinate-resistant variety at 25/20°C. However, at 45/30C the glufosinate-resistant variety was taller than the 'Hutcheson' variety. Fresh weights were highest of all the varieties in the sulfonylurea tolerant variety at 25/20°C, but not at 35/30°C or 45/30°C. Regardless of temperature, orthogonal contrasts showed that the conventional Asgrow variety had higher fresh weights than the Asgrow glyphosate-resistant varieties. At 25/20°C, the conventional Hartz 'H5164" variety had a higher fresh weight than Hartz glyphosate-resistant 'H5164RR' variety. At 35/30°C and 45/30°C, orthogonal contrasts showed that the conventional Hartz variety had a higher fresh weight than the Hartz glyphosate-resistant varieties.

Stem splitting was not observed at 35/30°C and 25/20°C. All of the sulfonylurea tolerant and glyphosate-resistant varieties had 100% stem splitting by the V2 stage of development at 45/30°C with the exception of 'AG5801' that had 90% stem splitting compared to conventional varieties or the glufosinate-resistant variety that expressed 60-70% stem splitting. Stem splitting observed at the V1 stage of development was visible as a small tear in the epidermal tissue at the base of the swelling stem. At the V2 stage of development, the swelling had increased and the epidermal tear had developed into a deep split of the stem.

Overall, in the growth chamber experiment, glyphosate-resistant varieties did not perform as well as glufosinate-resistant or conventional varieties. Differences in variety types were not very evident at lower temperature. However, differences in glyphosate-resistant and non-glyphosate-resistant varieties were more pronounced at higher temperatures.

An initial hypothesis was that if glyphosate-resistant CP4 EPSPS shuts down during heat stress, lignin quantity might be reduced, resulting in a decrease in stem strength and integrity and the observed stem splitting. To determine the quantity of lignin in the stems of the varieties, an acid-detergent fiber (ADF) analysis was conducted.

Results from the ADF analysis did not show any difference in lignin content of the varieties grown at 45/30°C. This result precluded the original hypothesis of stem splitting due to reduced lignin production resulting from heat stress deactivation of CP4 EPSPS. However, there was a higher percentage of lignin detected in the glyphosate-resistant varieties compared to the glufosinate-resistant and conventional varieties when they were grown at 25/20°C.

Table 1. Mean height, weight, and SPAD values of glyphosate-resistant, glufosinate-resistant, sulfonylurea tolerant, and conventional varieties of soybean grown in growth chambers maintained at 25/20°C, 35/30°C, and 45/30°C.

	Variety	Height			Weight			SPAD Values		
		25/20°C	35/30°C	45/30°C	25/20°C	35/30°C	45/30°C	25/20°C	35/30°C	45/30°C
			cm			g			0-50	
STS	AG4501	33	67	15	4.3	7.0	2.5	28.7	34.9	34.9
RR	AG5601	18	39	14	2.8	4.9	2.1	32.3	34.4	34.2
	AG5801	17	38	17	2.6	4.8	2.4	31.5	35.7	35.4
	AG5901	18	57	16	2.7	5.9	2.0	30.1	35.1	33.2
	H5164RR	19	40	15	2.9	5.0	1.7	28.3	35.8	33.4
	H5088RR	23	53	16	3.6	6.2	2.0	30.1	37.9	36.3
	H6686RR	23	66	17	3.7	6.4	2.5	30.2	36.1	31.8
LL	AG5547-127LL	26	56	20	4.0	6.8	3.8	36.7	39.6	40.5
Conventional	AG5843	30	77	19	4.2	8.0	2.9	34.9	38.6	40.1
	H5164	27	70	20	3.7	7.6	2.8	35.9	38.9	39.4
	Hutcheson	25	77	16	3.7	7.7	2.2	33.9	37.4	38.6
	Bryan	21	60	20	3.4	6.0	2.7	32.2	36.3	37.8
LSD (p=0.05)		2	5	1	0.5	0.6	0.4	2.7	2.4	1.3
Specific comparisions										
Hartz Conventional vs. Hartz Glyphosate-resistant (p > F)		0.050	0.001	0.001	0.847	0.043	0.001	0.303	0.911	0.695
Asgrow Conventional vs. Asgrow Glyphosate-resistant (p > F)		0.004	0.001	0.038	0.001	0.001	0.003	0.001	0.301	0.001

Table 2. Mean percentage of split stems at the V1 and V2 stage of development grown at 45/30°C and percent stem lignin content and percent change in lignin content of glyphosate-resistant, glufosinate-resistant, sulfonylurea tolerant, and conventional varieties of soybean grown in growth chambers maintained at 25/20°C and 45/30°C.

		Split Stem		Stem Lignin Content		
	Variety	V1	V2	25/20°C	45/30°C	difference
		%		%		%
STS	AG4501	90	100	12.49	13.44	0.95
RR	AG5601	60	100	11.46	11.93	0.47
	AG5801	60	90	10.77	11.58	0.81
	AG5901	80	100	11.95	12.19	0.24
	H5164RR	90	100	12.18	12.69	0.51
	H5088RR	90	100	11.70	12.18	0.48
	H6686RR	80	100	11.48	14.60	3.12
LL	AG5547-127LL	30	60	9.84	11.75	1.91
Conventional	AG5843	40	70	9.78	11.74	1.69
	H5164	50	60	9.64	11.47	1.83
	Hutcheson	50	70	9.57	11.88	2.31
	Bryan	40	70	9.69	11.80	2.12
LSD (p=0.05)		39	28	0.82	1.21	1.11

These data show that in the varieties examined the glyphosate-resistant ones posses a higher percentage of lignin in their stem tissue under normal growing conditions. There was a significant (r^2 = 0.56) correlation between the change in lignin content between 25/20°C and 45/30°C and the percent stem splitting and the V2 stage of development. The glyphosate-resistant varieties may have enough extra lignin in their stems prior to the onset of heat stress to account for stem inelasticity. The increased lignin content in these glyphosate-resistant varieties seems to predispose them to the epidermal tearing and eventual stem splitting observed in the growth chamber studies as they pass from normal to heat-stressed growing environments. These data indicate that the advantage of glyphosate-resistance may come at the expense of physiological heat stress tolerance in the varieties examined. The addition of glyphosate-resistance in these varieties might have altered the product distribution in the shikimate acid pathway. The implications of these results are far-reaching. The current system that imparts glyphosate resistance in glyphosate-resistant soybean makes the inherently sensitive to heat stress.

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Responses of five plant species sprayed with sublethal doses of metsulfuron methyl

C Boutin
National Wildlife Research Centre, Canadian Wildlife Service, 100 Gamelin Blvd. Hull, Québec, Canada. K1A 0H3

H-B Lee; T E Peart; S P Batchelor; R J Maguire
National Water Research Institute, Department of the Environment, Canada Centre for Inland Waters, 867 Lakeshore Road, P.O. Box 5050, Burlington, Ontario, Canada. L7R 4A6

ABSRACT

Two wetland plant species, *Mimulus ringens* (Monkey-flower) and *Bidens cernua* (Bur-marigold), two terrestrial species, *Sinapis arvensis* (Wild mustard) and *Phaseolus vulgaris* (Beans), and one species found in both wet and dry habitats, *Echinochloa crus-galli* (Barnyardgrass), were exposed to 1% (0.045 g-ai/ha) and 10% (0.45 g-ai/ha) of recommended label rate of the sulfonylurea metsulfuron methyl. The objective of the study was to investigate the effect of sublethal doses of metsulfuron methyl. Chemical analyses of herbicide residues showed that, in many cases, less than the intended doses reached the plants. Nevertheless all species exhibited marked effects on the vegetative and reproductive growth when sprayed at 10% label rate, and to a lesser extent at 1% label rate. Seed weight was significantly reduced for *B. cernua* and *S. arvensis*. The importance of the various strategies developed by the five species is discussed.

INTRODUCTION

Many sulfonylureas, including metsulfuron methyl, are increasingly used, largely due to their low toxicity to animals and their application rate (Beyer *et al.*, 1998). Metsulfuron methyl is commercialized under the trade name Ally™ and is recommended for use on wheat and barley in the Prairies of western Canada for the control of several broad-leaved species, i.e., 27 species from nine families. The industrial formulation, named Escort™ is used to control or suppress several plant species (14 species from five families) in forest, pasture, rangeland, rough turf and non-crop areas. Ally is applied at 4.5 g-ai ha^{-1} while Escort can be sprayed at up to 560 g-ai ha^{-1} in Canada, both with ground equipment only.

Concern is increasing over the use of sulfonylureas because of their side-effects on plants at very low doses (Bhatti *et al.*, 1996; Fletcher *et al.*, 1996). Metsulfuron methyl can prevent the development of seeds and reduce seed weight (Blair & Martin, 1988; ;Khan & Donald, 1992; King & Evans, 1983). Chlorsulfuron, another sulfonylurea herbicide, can cause a substantial reduction in yield (Al-Khatib *et al.*, 1992; Bhatti *et al.*, 1995) and seed output in several species (Fletcher *et al.*, 1993; Kjær, 1998).

The prairies of western Canada contain a large quantity of small wetlands with associated uplands that are intimately associated with croplands and this is the region where metsulfuron methyl is frequently applied. The objective of this study was to investigate the effect of sublethal doses of metsulfuron methyl on several types of plant species.

MATERIALS AND METHODS

The plants chosen for this greenhouse study were *Bidens cernua* (Asteraceae, wetland), *Mimulus ringens* (Scrophulariaceae, wetland), *Sinapis arvensis* (Brassicaceae, terrestrial), *Phaseolus vulgaris* (Fabaceae, terrestrial crop), and *Echinochloa crus-galli* (Poaceae, terrestrial and wetland). Three plants of *M. ringens*, *S. arvensis*, and *P. vulgaris* were grown in each pot, while two *B. cernua* plants and one *E. crus-galli* plant were grown in each pot. Plants were sprayed at four different growth stages: (I) at seedling stage, i.e., cotyledons for dicots and two blades for the monocot; (II) two true leave stage or 4-5 blades for the grass species; (III) at flower bud initiation; (IV) at commencement of flowering. Four replicate pots were planted for each treatment including four control pots. The photoperiod was maintained at 16 hours of daylight and 8 hours of darkness with temperature variation between 15 and 25 °C. Plants were copiously watered prior to herbicide treatment and were left unwatered for 24 hours after spraying.

Commercially available Ally™ (60% metsulfuron methyl) was purchased locally. The surfactant Agral 90 was used at the concentration of 2 ml l^{-1}, as recommended on the label for metsulfuron methyl. Two herbicide treatments were used, 1% and 10% of the typical field rate in agriculture in Canada (0.045 and 0.45 g active ingredient ha-^{1}). For the spray, a Chapin 8L hand sprayer was used (model #2103) equipped with a flat fan nozzle and tank pressurized to 2 bar (30 psi or 204 kPa) filled to full capacity, i.e. 4 l. The operator traveled at one meter per second while spraying, delivering 0.02l m^{-2} (200l ha^{-1}). Plants were placed in line on the floor along with nine glass fiber papers 142 mm in diameter laid next to the plants at 20 cm, approximately the height of the spray plants. A sample of the tank mix was taken for analysis of chemical concentrations. Metsulfuron methyl in the samples was extracted by solid phase extraction. For the tank mix, a simple and rapid high performance liquid chromatography (HPLC) method was used. For the glass fiber paper samples, a more sensitive gas chromatography/mass spectrometry (GC/MS) method was used instead (see Boutin *et al.* (in press) for detailed information). Analytical grade standard of metsulfuron methyl (purity 99.0%) was obtained as a gift from E.I. DuPont de Nemours & Company, Experimental Station, Wilmington, Delaware 19880-0402, USA.

Aboveground parts of the plants were harvested upon seed set of the control plants, for estimation of the biomass of vegetative and reproductive parts separately. Average seed dry weight was measured for plants that had produced seeds. A germination test was carried out with seeds produced by *Bidens cernua*. A one-way ANOVA was performed for differences between the nine treatments, control, 1% and 10% label rate at four phenological stages each. A Tukey multiple comparison procedure was carried out to examine the differences between treatments.

RESULTS AND DISCUSSION

Chemical analyses

Results of the chemical analyses showed that the concentration of metsulfuron methyl in the nominal 1% tank mix (0.045 g-ai ha^{-1}) ranged between 0.043 g-ai ha^{-1} and 0.077 g-ai ha^{-1}, while for the nominal 10% (0.45 g-ai ha^{-1}) the concentration varied between 0.44 g-ai ha^{-1} and 0.49 g-ai ha-^{1}. Analyses of the residue reaching the glass fiber papers (and thus probably the sprayed plants) showed more variation, with concentrations spanning between 0.017 g-ai ha^{-1} and 0.069 g-ai ha^{-1} for the nominal 1% label rate, and between 0.25 g-ai ha^{-1} and 0.51 g-ai ha^{-1} for the nominal 10% label rate of metsulfuron methyl. The amount of herbicides reaching the plants (measured on the glass fiber papers) was, in most cases, below the amount actually intended or calculated in the tank mix but still resulted in obvious effects on plants sprayed.

Various responses to small doses of metsulfuron methyl

The five study species displayed very different strategies in response to low doses of metsulfuron methyl. *Phaseolus vulgaris* is an annual crop artificially selected for high yield of beans. Expectedly the ratio of reproductive to vegetative parts at the end of the life-cycle is relatively high in untreated plants (Table 1, Fig. 1). The general response of this species to sublethal levels of metsulfuron methyl was to decrease the reproductive output, but seeds that were produced were of a normal size (Fig. 2) and healthy looking. A few pods were produced that were devoid of seeds. *Sinapis arvensis* is an annual weed commonly found associated with several crops. Seed production an important trait for this species, as for all annuals. In the control plants, reproductive tissue constitutes 85% of the biomass at the end of the life-cycle (Table 1, Fig. 1). The species behaved similarly to *Phaseolus vulgaris*, *i.e.*, seeds that were produced were of normal size (Fig. 2) except when spray with 1% metsulfuron methyl occurred at flowering time (timing IV). In this case seeds were very samll and unhealthy looking.

Echinochloa crus-galli is another annual species of weedy propensity. This species was less affected by metsulfuron methyl, a herbicide that primarily controls broad-leaved species with some suppression of grasses (Doig *et al.*, 1983). The effect of metsulfuron methyl on this species was chiefly to reduce the vegetative biomass (timing I) with no change in the reproductive biomass and seed size. Surprisingly, the ratio of reproductive to vegetative biomass of the control plants was very reduced in this species (Table 1).

In contrast to the three mostly terrestrial species, the two wetland species tested responded differently to the stress induced by metsulfuron methyl. The main effect on *Bidens cernua* was to maintain its total reproductive biomass but to produce numerous seeds that were much reduced in size when sprayed at 10% label rate during flower initiation (Fig 1 and 2, Table 1). Seeds were subjected to a germination test over one month which showed that many of the seeds that developed when sprayed at 1% and 10% label rate during the flower bud stage (timing III) were not viable (100% germination of control seeds, between 65% and 75% germination in other treatments). Conversely, *Mimulus ringens* increased, maintained or decreased its total reproductive output with the different treatments (Fig 1, Table 1). This species, analogously to *Bidens cernua*, produced numerous pods, but in marked contrast with the latter, they

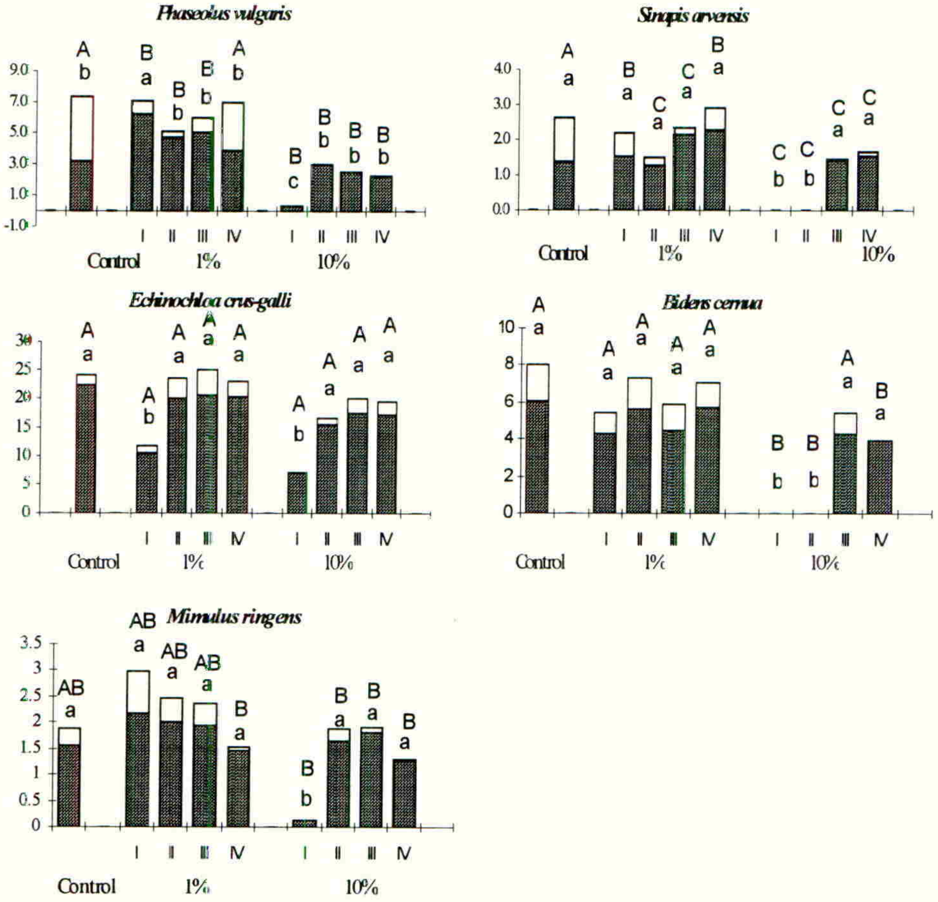

Figure 1. Average dry weight (g) of vegetative (solid bars) and reproductive parts (open bars) of the five plant species tested. Control, I = cotyledon stage, II = two true-leaf stage, III = flower bud, IV = onset of flowering. Plants were sprayed with metsulfuron methyl at 1% (0.045 g-ai ha^{-1}) and 10% (0.45 g-ai ha^{-1}) of recommended rate . Different letters above bars mean significant differences between treatments; Uppercase letters, reproductive biomass; Lowercase letters, vegetative biomass.

were largely devoid of seeds. Seed weight was not measured for *Mimula ringens* because of their very small size.

In conclusion, this study demonstrated that the pattern of resource allocation varied among the five study species when subjected to sublethal doses of metsulfuron methyl. All species were significantly affected at the low doses tested. The two terrestrial species, *P. vulgaris* and *S. arvensis*, decreased their reproductive biomass but produced

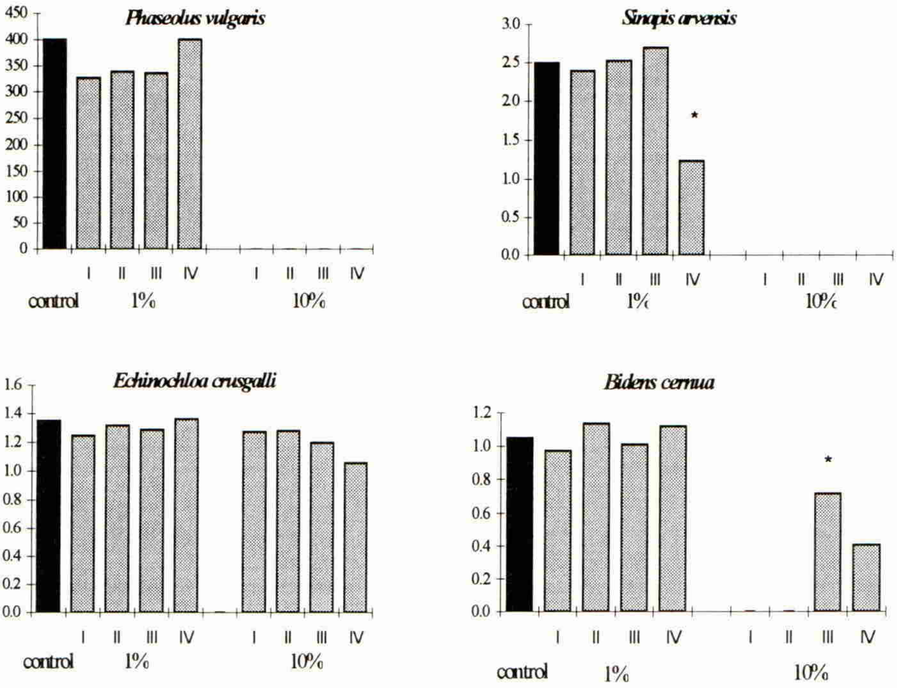

Figure 2. Average seed weight of four of the test species. Significant differences between treatments a star symbol above bars.

some healthy seeds while the three species of wetland habitats did not show so much variation in reproductive biomass. However, *B. cernua* produced flower heads with small seeds, many of them not viable, while *M. ringens* developed pods largely empty of seeds. Kjaer (1998) noted that in *Polygonum convolvulus* sprayed with chlorsulfuron, another sulfonylurea herbicide, maturation of seeds was delayed. There is a possibility that some treated plants in this study were harvested too soon, even though senescence was already initiated. Sublethal effects caused by small amounts of herbicides are seldom considered in plants, especially in relation to the reproductive output and in the ecosystem context. Delaying seed set can have serious consequences for an annual growing in competition with other species but even more dramatic effects on population dynamics would result from the total inhibition of reproduction. Furthermore, smaller seeds produced by small doses of herbicides might produce plants of reduced size and this might be significant at the community/ecosystem levels. These sub-lethal effects of herbicides on population dynamics should be investigated further.

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The control of weeds with glufosinate-ammonium in genetically modified crops of forage maize in the UK

M A Read, J G Ball
AgrEvo UK Ltd, East Winch Hall, East Winch, King's Lynn, Norfolk, PE32 1HN

ABSTRACT

Trials carried out since 1995 in UK have shown that glufosinate-ammonium, as Liberty ® (proposed tradename), can achieve high levels of control of both grass and broad-leaved weeds in forage maize, which has been genetically modified to be tolerant to this herbicide. Results with a two-spray, post-emergence programme compare very favourably to conventional herbicide programmes, normally based on atrazine, applied pre-emergence. This technology can provide an opportunity to treat weeds later, thus removing the need to treat with 'insurance treatments'. This has a number of potential environmental benefits and provides a more flexible approach for the farmer. It also means that species resistant to atrazine are controlled. Some other benefits of genetically modified crops are also discussed.

INTRODUCTION

Forage maize is often grown on mixed farms and also as one of the few arable crops on livestock farms. It is therefore often left to contractors to manage the weed control in this crop. It is a crop that is very sensitive to weed competition and in the early 1970's, Milbourn (1971) made recommendations for quite high doses of atrazine to give effective weed control, whilst also trying to manage crop tolerance and in following crop residues. Further work was reported by MAFF(1975), in order to provide post-emergence alternatives or additions to atrazine, which continues to be the mainstay for weed control, despite the realisation that black nightshade (*Solanum nigrum*) resistant to this herbicide was recognised by Weller & Phipps(1980), nearly twenty years ago.

The advent of genetically modified plants, such that they can be made tolerant to a broader spectrum herbicide has given the possibility of providing a new, flexible, simple to use, contact-only solution to weed control in this sensitive crop with good crop safety. The use of a herbicide like glufosinate-ammonium in this crop also provides excellent control of some more difficult species that have not been well controlled by conventional selective herbicides, and also species that have become resistant to other herbicides, in particular black nightshade (*Solanum nigrum*) which, in continuous maize crops is now commonly resistant to atrazine.

Details of the transformation system for glufosinate-ammonium were presented by Rasche *et al.* (1995) together with a synopsis of the developments to that time. The Liberty Link ® system was successfully launched in Canada, initially in canola (spring oilseed rape) in 1995, and in maize in the USA in 1997, and Rasche & Gadsby (1997) detail benefits for the farmer and environment. The area of maize treated with glufosinate in USA rose from 700,000 acres in 1997 to approximately 2 million acres in 1998. Trials with glufosinate-ammonium in forage maize have been carried out in the UK since 1995 and some of the initial findings are presented here.

MATERIALS AND METHODS

All trials reported in this paper were carried out on genetically modified, herbicide tolerant (GMHT) varieties of forage maize from Advanta, Mais Angevin, or Kleinwanzlebener Saatzűcht (KWS).

Trials were drilled at locations in Cambridgeshire, Cheshire, Gloucestershire, Oxfordshire and Norfolk. Soil types ranged from loamy sand to silt loam, (Soil Texture, (1985) System, MAFF). The trials were designed as randomised blocks with three or four replicates and plot sizes between 16m^2 and 30m^2. Applications were made using pressurised knapsack small-plot sprayers at a pressure of 250kPa delivering 200 l/ha through four or six flat-fan nozzles spaced 50cm apart on 2m or 3m spray booms.

The following herbicide treatments were applied: glufosinate-ammonium (200g/l A.S) at 400-800 gai/ha; atrazine as Gesaprim (500g/l S.C) at 750-1700gai/ha; pyridate (45% W.P) as Lentagran at 900gai/ha, and bromoxynil (250g/l L.I) as Alpha Bromotril P at 250gai/ha. In the tables the dose rates are given as litres or kilograms of product per hectare.

Weed control was assessed visually using a percentage scale 14-30 days after the last application. Crop vigour assessments were made at regular intervals after application using a percentage scoring system and yields were taken by hand-cutting two 5m lengths from the middle two rows of the plot and weighed using a spring balance to give a fresh weight. Growth stages of applications in trials are according to Zadoks *et al.* (1974) for volunteer cereals; Lawson & Read (1992) for grass-weeds; Bleiholder (1990) for broad-leaved weeds and maize. Years given in brackets are the harvest year of the trials. Other abbreviations are:- ATXPA=*Atriplex patula*; AVEFA=*Avena fatua*; CAPBP=*Capsella bursa-pastoris*; CHYSE=*Chrysanthemum segetum;* CHEAL=*Chenopodium album*; GALAP=*Galium aparine*; LAMPU=*Lamium purpureum*; MATIN=*Tripleurospermum perforata*; POAAN=*Poa annua*; POLPE=*Polygonum persicaria*; SOLNI=*Solanum nigrum*; SOLTU=*Solanum tuberosum*; STEME=*Stellaria media*; URTUR=*Urtica urens*; and VERPE=*Veronica persica*. Statistical analysis of individual trials was carried out using a Newman Keuls test on the raw data. In the tables, means not followed by the same letter are significantly different ($p = 0.05$).

RESULTS AND DISCUSSION

The yield data from the weed-free crop tolerance trials (Tables 1 & 2), over two years and across a range of GMHT varieties show excellent crop tolerance to glufosinate-ammonium, even at dose rates as high as a total of 16l ha^{-1} which is four times the likely commercial dose.

Table 1. Crop tolerance of glufosinate-ammonium in GMHT forage maize – Relative yield (1996). Trials were located in Norfolk and Oxfordshire using the same variety. Timing A was applied to the crop at GS12-14. Timing B was applied to the crop at GS16-23. No significant visual crop effects were noted at either site.

Treatment	Timing	Dose l ha^{-1}	RJW01	JGB01	Mean
glufosinate	A+B	4+4	104a	112a	108
glufosinate	A+B	8+8	103a	107a	105
Untreated Yield (t/ha)			32.8a	19.2a	26.0
No. of trials			1	1	2

Table 2. Crop tolerance of glufosinate-ammonium in GMHT forage maize – Relative yield (1998). Trials were located in Norfolk and Oxfordshire using four/five different varieties. Timing A was applied to the crop at GS12-14. Timing B was applied to the crop at GS16-18. No significant visual crop effects were noted on any of the varieties at either site.

Treatment	Timing	Dose l ha^{-1}	CG01	CG02	CG03	CG04	
atrazine	A	3	105a	108a	107a	100a	
atrazine	A	6	111a	105a	108a	97a	
glufosinate	B+C	4+4	106a	105a	110a	105a	
glufosinate	B+C	8+8	103a	103a	107a	98a	
Untreated Yield (t ha^{-1})			21.8a	18.3a	18.8a	21.0a	
			GB01	GB02	GB03	GB04	GB05
atrazine	A	3	97a	124abc	112a	99a	105a
atrazine	A	6	95a	111bc	113a	110a	98a
glufosinate	B+C	4+4	111a	141a	128a	109a	104a
glufosinate	B+C	8+8	109a	129ab	108a	115a	111a
Untreated Yield (t ha^{-1})			27.4a	20.6c	25.5a	27.8a	36.0a

Table 3. Control of broad-leaved and grass weeds in GMHT forage maize (1995). Trials were located in Norfolk and Cambridgeshire. Timing A was applied to the crop at GS10-11. Timing B was applied to the crop when broad-leaved weeds were between GS12-14 and POAAN was at GS13. Timing C was applied when the crop was between GS14-18, broad-leaved weeds were at GS16 and POAAN at GS23.

Treatment	Timing	Dose l ha^{-1}	CHEAL	MATIN	VERPE	POAAN	POLPE
atrazine	A	3.4	45b	54b	23c	19b	80a
glufosinate	B	2	97a	99a	69b	86a	91a
glufosinate	B+C	2+2	100a	100a	71b	87a	100a
glufosinate	C	3	100a	100b	98a	91a	99c
Untreated (weeds m^{-2})			16	4	27	10	8
No. of trials			2	2	1	1	1

The data on weed control compare single and double applications of glufosinate-ammonium at dose rates of 400g to 800gai/ha with a standard treatment of either atrazine pre-emergence at 1500-1700gai ha^{-1} or a sequence of atrazine pre-emergence followed by a mixture of atrazine + bromoxynil post-emergence, (Tables 3-7). Over the four years' work, it is clear that glufosinate-ammonium, as a post-emergence, two-spray programme, gives

Table 4. Control of broad-leaved and grass weeds in GMHT forage maize (1996). Trials were located in Norfolk and Cambridgeshire. Timing A was applied when the crop was at GS12-14 and broad-leaved weeds and AVEFA was at GS13. Timing B was applied when the crop was between GS14-18, broad-leaved weeds were at GS16 and AVEFA was at GS22. Timing C was applied when the crop was at GS34.

Treatment	Timing	Dose l ha^{-1}	CHE AL	URT UR	CAP BP	POLPE	CHY SE	LAM PU	AVE FA
atrazine + pyridate	A	2+ 2kg	85a	77a	100a	100a	100a	100a	33b
glufosinate	A	2	93a	73a	85a	100a	100a	93a	93a
glufosinate	A	3	94a	88a	100a	100a	100a	95a	98a
glufosinate	A+B	2+2	84a	88a	98a	100a	100a	92a	98a
glufosinate	A+B	3+3	97a	93a	100a	100a	100a	98a	100a
glufosinate	C	4	99a	96a	100a	100a	100a	100a	100a
Untreated (weeds m^{-2})			13	5	20	5	6	8	8
No. of Trials			2	1	1	1	1	1	1

Table 5. Control of broad-leaved and grass weeds in GMHT forage maize (1997). Trials were located in Norfolk, Cheshire, Oxfordshire and Twyning. Timing A was applied pre-emergence of the crop and weeds. Timing B was applied between crop GS11-14 and broad-leaved weeds GS14 and POAAN at GS13. Timing C was applied when the crop was at GS15-19, when broad-leaved weeds were at GS18 and POAAN was at GS21. Timing D was applied at crop GS15-16, when broad-leaved weeds were at GS22 and POAAN at GS26.

Treatment	Timing	Dose l ha^{-1}	CHEAL	POA AN	SOL NI	VER PE	SOL TU	URT UR
atrazine	A	3	76ab	100a	46b	100a	97a	81a
atrazine atrazine+Alpha bromotril P	A/ B	2/ 1+ 1	77ab	99a	97a	100a	83a	97a
glufosinate	B	2	89a	17b	75a	92a	97a	56ab
glufosinate	B	3	96a	58a	72a	97a	92a	66a
glufosinate	B+C	2+2	99a	91a	98a	100a	99a	77a
glufosinate	B+C	3+3	100a	98a	98a	98a	100a	88a
glufosinate	D	3	98a	63a	75a	75a	95a	61ab
glufosinate	D	4	100a	93a	92a	95a	98a	46ab
Untreated (weeds/m^{2})			42	14	69	8	18	55
No. of Trials			3	1	2	1	1	3

excellent control of a wide range of annual grass and broad-leaved weeds – similar to the standard commercial treatment, but at around half the amount of active ingredient. In some cases it is clear that a dose rate of 3l ha^{-1} is required on more difficult species (e.g. *Urtica urens*), and that even single applications of 2l ha^{-1} can be very effective in some seasons, (*e.g.* 1996), although this is dependent on weather conditions and whether there are subsequent later flushes of weeds. Late applications as "fire-engine treatments", are also possible if applications are delayed, although higher doses of up to 4l ha^{-1} are then often required to achieve acceptable levels of control. The poor control of resistant *Solanum*

Table 6. Control of broad-leaved and grass weeds in GMHT forage maize (1998). Trials were located in Norfolk and Cheshire. Timing A was applied pre-emergence of the crop and weeds. Timing B was applied when the crop was at GS12-14 and broad-leaved weeds were at GS16. Timing C was applied when the crop was at GS15-17 and broad-leaved weeds were at GS18. Timing D was applied at crop GS17-20, when broad-leaved weeds were at GS55.

Treatment	Timing	Dose l ha^{-1}	CHEAL	SOLNI	ATXPA	POLPE	MATIN	GALP	CAPBP
atrazine	A	3	98a	13c	100a	83ab	100a	100a	100a
atrazine atrazine+Alpha bromotril P	A/ B	2/ 1+ 1	100a	12c	100a	100a	100a	100a	100a
glufosinate	B	2	98a	63b	99a	48abc	73a	78a	100a
glufosinate	B	3	98a	86ab	100a	67ab	75a	77a	85a
glufosinate	B+C	2+2	100a	98a	100a	93ab	100a	92a	69c
glufosinate	B+C	3+3	100a	98a	100a	99a	100a	93a	95a
glufosinate	D	3	99a	71ab	98a	52abc	100a	33a	83a
glufosinate	D	4	99a	78ab	100a	81ab	100a	63a	100a
Untreated (weeds/m^2)			27	28	6	15	10	20	35
No. of Trials			1	1	1	1	1	1	1

Table 7. Control of broad-leaved weeds and yield response in GMHT forage maize (1998). The trial was located in Cheshire. Timing A was applied pre-emergence of the crop. Timing B was applied to the crop at GS14 and broad-leaved weeds at GS14-18. Timing C was applied to the crop at GS17 and broad-leaved weeds at GS51. The untreated was handweeded.

Treatment	Timing	Dose l ha^{-1}	CHEAL	URTUR	STEME	SOLNI	Relative yield
atrazine	A	3	100a	100a	100a	15b	74bc
atrazine	A	6	100a	100a	100a	18b	66c
glufosinate	B+C	4+4	100a	94a	98a	95a	116a
glufosinate	B+C	8+8	100a	97a	99a	99a	100ab
Untreated (weeds m^{-2},t ha^{-1}))			12	20	12	325	21.8ab

nigrum with atrazine can be seen in Tables 5-7, compared with excellent results with glufosinate-ammonium on this important weed in continuous maize situations. The yield results from an efficacy trial in 1998, (Table 7), from a site with a high infestation (325 plants m^{-2}) of resistant *Solanum nigrum* and other weed species clearly demonstrates the yield benefit of controlling this weed and the excellent crop safety of high doses of glufosinate-ammonium.

These trials show that single or sequential applications of glufosinate-ammonium, a contact-only herbicide, can replace higher doses of pre-emergence, soil acting residual herbicides which are commonly used in mixture, or in sequence with other products to achieve good control of broad-leaved and grass weeds. The maize crop is ideal for achieving good levels of weed control using low rates of active ingredient whilst also controlling atrazine resistant species. The extra flexibility in the application timing of glufosinate-ammonium allows weeds to be left in the crop for insects to feed on for up to four weeks depending on the season. This gives a clear environmental benefit over the traditional herbicide programmes without reducing the yield of the crop. The ability to delay application may also help conserve soil moisture and reduce wind erosion of the soil by leaving a mulch of weeds in the field.

ACKNOWLEDGEMENTS

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Modelling the impact of transgenic herbicide-tolerant oilseed rape on weed population dynamics

N M^{c}Roberts G Marshall
Plant Science Division SAC Auchincriuve, Ayr, KA6 5HW, UK

K Davies
Crops Division SAC Edinburgh, Bush Estate, Penicuik, EH26 0PH, UK

C J Doyle
Management Division SAC Auchincruive, Ayr KA6 5HW, UK

ABSTRACT

Posssible appraoches to mdelling the long term effect of genetically modified herbicide tolerant crops on weed populations are discussed. The difficuluties in the most widely used approaches for studying weed populations are noted. Specifically, in the context of maintenance of biodiversity, the focus of attention is on the weed community rather than individual species, but modelling of community dynamics depends on estimates of competition parameters that are problematic to obtain from practical experiments.

INTRODUCTION

The availability of genetically modified herbicide tolerant (GMHT) crop varieties for commercial release has stimulated a vigorous public debate in the UK over the environmental acceptability of the technology on which they are based. In addition to fears concerning gene escape, and the occurrrence of GMHT varieties as weeds, there is concern over the impact on weed biodiversity of the increased used of the broad-spectrum herbicides that are associated with GM crops. Predictions in the popoular press of the impact of GMHT crops on the native flora range from catastrophic loss of many weed species, to minor changes in the community structure and even increases in biodiversity. The monitorium on commercial planting of GMHT oilseed rape in the UK has provided an opportunity to carry out studies of the short term effects of GMHT crops on the arable weed flora before the widespread planting of the crop. Unfortunately, as Cousens & Mortimer (1995) have pointed out, such short term experimental studies can give only limited information about the population dynamics of the weed community in the long term. However, it is precisely the long term consequences of GMHT crops about which the public is concerned. In these circumstances some form of predictive model of the weed community seems to be the only means by which long term effects can be even roughly estimated from short term data. Modelling weed population dynamics generally has not yet reached the stage where precise quantitive predictions of weed communities can be made with certainty. Fortunately, qualitative predictions such as, which species will probably increase in abundance, which will decrease or become extinct in arable ecosystems, are more robust tahan quantitative predictions and are, at present anyway, in line with the sorts of question being asked of the producers of GMHT crops and scientsists studying them. In this paper we set out some of the issues involved in modelling the impact of GMHT crops on the arable weed flora as much to stimulate discussion as to provide answers. The paper draws on basic ecological theory, current concepts in mathematical modelling of weed populations and on field experiments conducted by SAC funded by the Scottish Executive Rural Affairs Department (SERAD) intended to generate data for modelling puposes.

MODELLING

Individual weed species

The initial discussion here closely follows that developed by Cousens & Mortimer (1995). We start by condsidering a population of an individual annual weed species in the absence of weed control. A simple logical examination of the possbilities for this population suggests that its size in the next season is dependent on its intrinsic rate of increase and a density-dependent feedback term that regulates the rate of population increase through competition as the population grows (Watkinson, 1997):

Formally, these ideas can be expressed as a difference equation (1)

$$N_{t+1} = RN_t f(N_t) \qquad 1.$$

The form of the density-dependent term [$f(N_t)$] can vary the form shown in equation 2 has been found to be useful in a range of species (Cousens & Mortimer, 1995).

$$N_{t+1} = RN_t (1+aN_t)^{-b} \qquad 2.$$

Equation 2 contains no element of extrinsic control (such as herbicide application) over population growth. Bearing in mind that herbicides may have sub-lethal effects on fecundity as well as lethal effects (Boutin *et al.*, this volume; Laisnbury *et al.* this volume) equation 2 can be adapted to include the effect of herbicide application on population growth. We assume that a proportion, p, of plants are killed by the herbicide, and thus (1-p) survive and compete giving the form shown in equation 3:

$$N_{t+1} = RN_t (1+aN_t)^{-b}-pRN_t \qquad 3.$$

From the perspective of the possible impact of GMHT crops on weed biodiversity, the equilibrium population is of interest. The equilibrium population, N_e, for a weed population described by equation 3, is given by

$$N_e = \{[R/(1+pR)]^{1/b}-1\}/a \qquad 4.$$

Figure 1. shows predicted values for N_e against p for a set of realistic parameter values for R, a and b, and on the assumption that these values do not vary with p. It can be seen from Fig.1 that, with the particular parameter values used in this case, the herbicide does not reduce N_e to zero unless p is maintained at a value of approximately 0.9. While this level of control is in keeping with levels of control reported in the field (Read & Ball, this

volume; McKinley *et al.*, 1999), it must be noted that use of equation 4. in this way implies a situation of continuous monocropping with the GMHT crop. The introduction of a rotation of alternative crops, with their associated control options, would probably cause p to vary between weed generations and might lead to significant increases in predicted values for N_e.

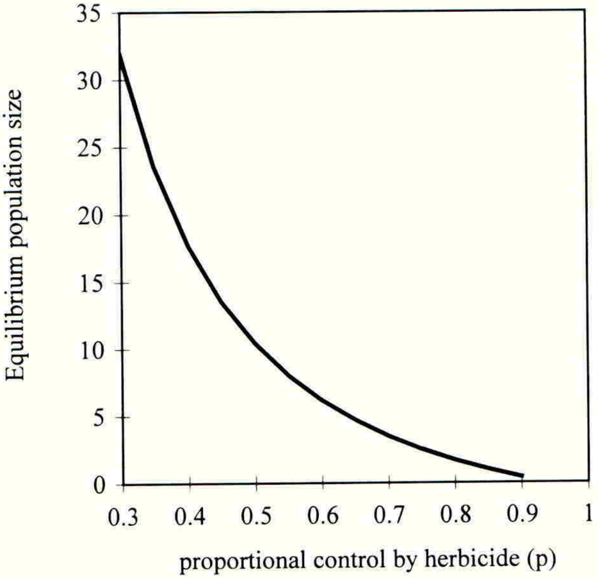

Figure 1. Theoretical reduction in a weed equlibrium population (Ne) with increasing efficacy of herbicide activity. The curve is generated from equation 4 with parameter values $R = 95$, $a = 0.21$, $b = 0.5$).

There are many ways in which equations 3 and 4 fail to capture the complexity of the interactions that determine weed population dynamics. The underlying model for equations 3 and 4 is that of a homogenous single-species population. This misrepresents the way in which weeds typically occur; in spatially heterogeneous (patchy) mixed species communities.

Mixed species patches

Patchiness in weed populations is a widely recognized phenomenon and has been the stimulus to many recent advances in precision application of pesticides (*e.g.* Audsley and Beaulah, 1996.) and sampling methodology (Gold *et al.*, 1996; Johnson *et al.*, 1996). In the case where weed populations are assessed by counting numbers of plants per sampling unit (quadrat), patchiness can be expressed as the deviation of the observed number of plants per quadrat from the number expected for a Poisson distribution with the same mean value as the value observed in the data. In the Poisson distribution, the mean is equal to the variance and so patchiness (or overdispersion) in observed weed counts can be easily identified by comparing the observed mean with its variance and noting when the latter exceeds the former. In cases where count data are overdispersed, the Negative Binomial Distribution (NBD) often gives a good description of the observed frequency of weeds per quadrat. The *k* parameter of the NBD captures the overdispersion in the data and offers an additional measure of patchiness. Table 1 gives the mean and variance for plants per quadrat, and estimated values of *k* for seven of the most abundant weeds found at an SAC trial site where a rotation including GMHT oilseed rape is being assessed. The weeds were assessed by counting weed numbers in 9 0.25m^2 quadrats in each of 40 experimental plots. The data in Table 1 are the mean values for all 360 quadrats for each weed.

Table 1. Mean weed numbers per quadrat and variances for seven weeds found at a GMHT oilseed rape trial site prior to sowing the first GMHT crop.

Weed	Mean no. plants quadrat (*n*)	Variance *var*(*n*)	*var*(*n*)/ *n*	Estimated *k*
Matricaria sp.	0.6	3.86	5.1	0.13
Capsella bursa-pastoris	12.3	165.28	13.4	0.98
Poa annua	10.9	74.20	6.8	1.88
Stellaria media	7.8	32.51	4.2	2.45
Chenopodium album	0.5	2.68	5.4	0.10
Fumaria officinalis	0.2	0.41	2.0	0.23
Spergula arvensis	0.3	4.2	14.0	0.02

Table 1 indicates that all seven weeds had patchy spatial patterns at the scale at which they were sampled; estimated variances in weed counts were between 2 and 14 times the mean weed number per quadrat.

The distributional approach to the analysis of patchiness indicated by the data in Table 1 can easily be extended to examine the dynamics of patch occupancy by *individual* species by making certain, well-informed, assumptions about the dynamics of population growth within patches (such as those used to develop equations 3 and 4). However, not only are the dynamics of weed species affected by control measures taken by farmers, they are also affected by the dynamics of the other species in the communities in which they commonly grow. Any serious attempt to predict the long term behaviour of weed populations in association with GMHT crops must take inter-specific competition between weeds into account.

Much of the framework within which competition is studied is based on publications by MacArthur (1970) and May (1973). One of the central concepts in this theoretical work is the community matrix; a symmetrical matrix containing the inter-specific competition parameters for the species in the community under investigation. The long term stability of the community under investigation is summarized by community matrix. Under the assumption that population growth is a Markov process (*i.e.* that population sizes are dependent only on the size of the immediately preceeding generation) the community matrix can also be used to model population dynamics. Figure 2 shows the results of a simulation based on an hypothetical community matrix for the seven species listed in Table 1. The values of the coefficients in the community matrix are best guesses, based on expert knowledge of the growth of the species in question, since estimated values from experimental studies are not available. The coefficients are scaled relative to the value for the most competitive that was considered to be possible given the species present at the trial site. The use of guestimates highlights the point made by Cousens and Mortimer (1995) and others, that detailed knowledge of the quantitative competitive effects of many weed species on one another is simply not available because the experiments required to obtain the information have never been performed.

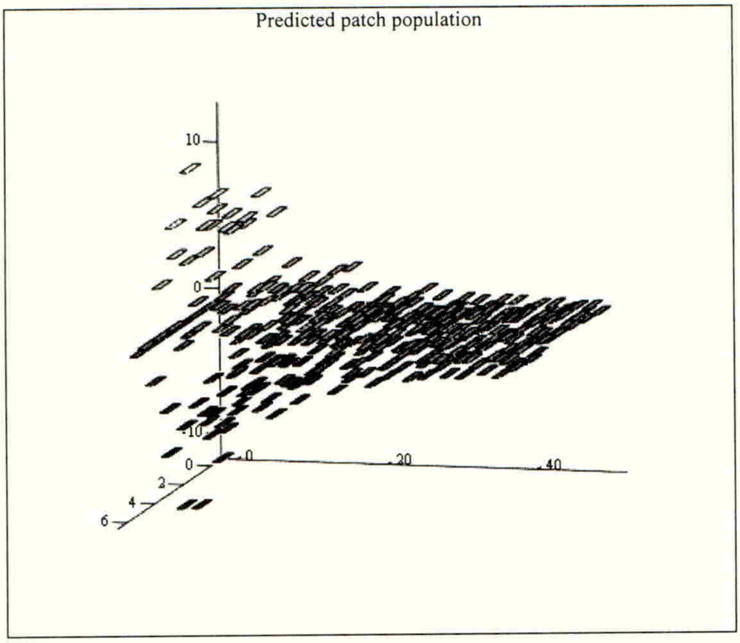

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Figure 2. Output from a simulation of within patch competition for a community of seven weeds. Competition coefficients for the weeds were gestimates. The simulation includes non-denisty dependent recruitment from a seedbank and the effect of control under continuous cropping with GMHT oilseed rape. Competition and herbicide effects from the GMHT are subsumed into a single parameter. y-axis, weed numbers; x-axis time (years); z-axis weed identity (1-7 corresponding to the order in Table1).

The output shown in Fig.2. is intended for illustrative purposes only but suggests that, if the model accurately reflects reality, the weed community would be likely to reach a stable state in which all 7 species oscillate around fairly small mean numbers of plants on an annual basis.

The Markov process model underlying Figure 2 considers the dynamics within one patch in which it is assumed that the competition effects described in the community matrix apply homogeneously to all plants present. On a suitably small spatial scale this assumption might be realistic, but in order to incorporate the known patchy struture of the weed community at the field scale it will be necessary to model a population of patches and allow for dispersal between patches. This basic model structure – homogenous patches with dispersal between patches – has also been investigated by Mortimer *et al.*, (1996) using a set of linked difference equations each of which is an extension of equation 3 above that includes inter- as well as intra-specific competition parameters. Although a potentially powerful approach to the prediction of weed community dynamics under GMHT crop rotations, the difference equation approach involves the same requirement for inter-specific competition parameters as the matix-based model. In either case, the value of long term qualitative predictions that might arise from the models is dependent on the rather tricky process of estimating competition parameters for a large number of species under realistic conditions.

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Modelling the environmental effects of farm management within whole farm planning: *e.g.* herbicide use

J E Sells

Silsoe Research Institute, Wrest Park, Silsoe, Bedford MK45 4HS, UK

ABSTRACT

The Silsoe Whole Farm Planning Model is used to optimise multiple objectives of maximising net farm profit and minimising herbicide use for blackgrass and wild oat control in cereals. Herbicide required is calculated on the basis that it must achieve consistent long-term weed control involving crop rotations, type of cultivation and timing of crop planting. The model shows that although herbicide taxes achieve some reduction in herbicide use, for a similar loss in farm profit far greater reductions can be made if the farmer is goal driven and thus alters the farm cropping or systems to maintain profit but reduce the need for herbicides. For a 5% loss in net profit, the farmer can achieve herbicide reductions of 37% and 100% for wild oat and blackgrass herbicides respectively, whereas a 200% herbicide price increase reduces profit by the same amount resulting in herbicide decreases of only 10% and 16%.

INTRODUCTION

Environmental concerns particularly over water quality and within the environment are increasing the pressure on farmers to farm in a more environmentally friendly way and this may become direct pressure such as pesticide tax. However, in many cases it is possible to make choices, which are better for the environment but have little effect on profit. Cropping, crop rotation, machinery system choices and timing of operations all influence the burden placed on the environment by things as pesticides emissions, nitrate leaching and the effects on biodiversity. However, we cannot make change in isolation. For example assuming herbicide use is optimal, reducing it to half will cause weed levels to increase in the long-term unless other changes are made to the farming system. Thus it is only by modelling the whole farm system that we can explore integrated profit and environment effects of farm management or objective changes. In this paper we explore the effects of farm management on herbicide use in cereals using such a model. Herbicide use is considered as the first step to evaluating an environmental impact of herbicide pollution. Use is a good indicator of the amount reaching the environment because of the diverse mechanisms by which pesticide is lost from the farming system. The assumption is that the lower the use of herbicides the better it is for the environment, however from a farmer's viewpoint weed control is still important for successful and profitable farming.

Under the EC AIR programme, Silsoe have developed a whole farm planning tool to allow a user to optimise any arable farming system with respect to profitability and environmental impacts (Sells & Audsley, in prep.). The model originates as a farm planning tool used to assess the commercial viability of machinery and machinery systems (Audsley, 1981) or alternative crops such as sunflowers (Sells, 1993), by comparing optimal solutions with respect to profit of alternative farming scenarios. The model now includes the evaluation or optimisation of environmental impacts, accounting for changes with respect to operation timing, alternative cropping and crop rotations, workability of different machinery systems and soils. Outputs from the model include the farm cropping, crop rotation, machinery and labour requirements, a farm work plan, in addition to the annual net profit and environmental outcomes. The model uses a substantial database of farm planning information to model generic or actual farms. By altering the inputs and objective, the model is used to explore the resulting profitability and impact to the environment of alternative strategies for particular farming systems.

Data for the model (the Silsoe Whole Farm Model) is derived from other models and farm statistics (Nix, 1998). Sells (1996) used stochastic dynamic programming to optimise long-term weed management for wild oats and blackgrass. Using the same principles data is derived to relate the amount of herbicide needed to achieve a constant long-term weed control for alternative cropping, rotations and machinery systems. This paper explores the herbicide use for two cereal weeds, wild oats and blackgrass, in two alternative farm situations (a cereal farm on clay soil and an arable farm producing cereals, potatoes and sugar beet on a sandy loam soil). The Silsoe Whole Farm Model is used to explore the impact on profit and herbicide use of herbicide taxes and goal driven reductions in herbicide use, and to analyse the impact of alternative cultivation techniques on herbicide use and profit.

METHOD

Two representative farm types are defined for analysis; a cereal farm on clay soil and a cereal/root farm on sandy loam. Table 1 details the crops, their expected base yields and the price information used in the analyses. Note that these base yields are adjusted within the model for such things as timing of drilling and harvest, and the previous crop in rotation.

Table 1 Crop data used for representative farms and soil types

Crops	Primary yield t/ha		Price £/ha	Subsidy £/ha	Gross Margin £/ha	
Soil type:-	*Clay*	*Sandy loam*			*Clay*	*Sandy loam*
Winter wheat	9.88	8.00	102	251	1062.1	870.8
Winter barley	8.40	6.90	98	251	966.4	804.4
Spring barley	5.48	4.99	108	251	751.7	687.0
Winter rape	3.96	2.54	160	439	806.2	578.2
Spring Rape	2.70	1.70	160	439	700.4	540.4
Potatoes	-	40.7	75	-	-	1128.0
Sugar beet	-	46.0	36	-	-	955.7
Spring beans	3.70	3.20	103	359	571.0	519.5
Setaside	-	-	-	341	319	

Like the yields, the environmental impacts are also associated with operation timing, rotations and machinery systems. Thus to calculate herbicide use we need to relate it to changes in farm management. Sells (1995) calculated optimum long-term weed management strategies to maintain weed control over crop rotations using alternative cultivation techniques and different levels of sprays. The model is based on a weed population model (Cousens *et al.*, 1986) simplified on the assumption that weed levels remain low enough to be controlled. Data for the model for wild oat and blackgrass population dynamics under farm management can be used to determine appropriate data for the Silsoe Whole Farm Model.

The environmental impact calculated in the farm planning model is the number of doses of wild oat and blackgrass herbicides required to maintain a constant level of weeds over the long-term. Thus the kill rate from the herbicide, in addition to cultivation techniques, crop rotation and operation timings adds up to maintaining weed levels at a constant level. The kill rate required for particular crop rotations under particular cereal planting timings and cultivations can be calculated assuming the weed seed level is equal before and after the rotation. Assuming that a typical herbicide will give say an 85% kill rate for each application or dose, the number of doses required to achieve that level of kill per year is calculated. Figure 1 gives an example of the data. It shows how the amount of wild oat herbicide dose required decreases with later cereal planting, depending upon the cultivation technique used, either ploughing or shallow cultivation.

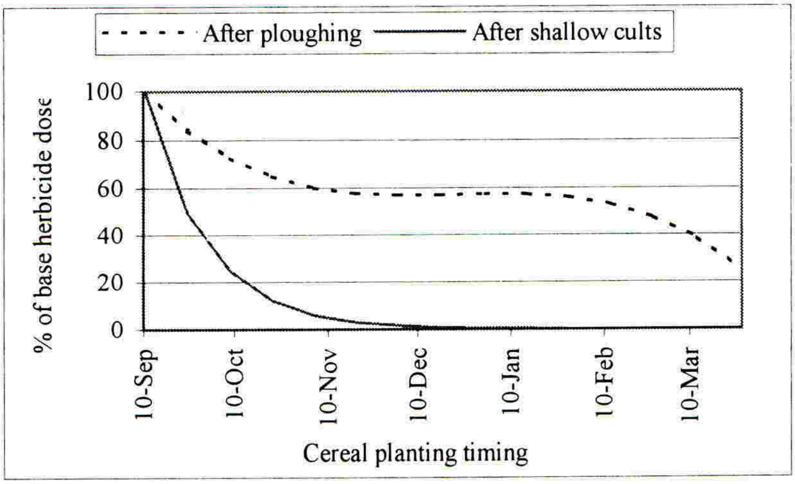

Figure 1 Decrease in wild oat herbicide use necessary to maintain constant weed levels for different planting timings following ploughing or shallow cultivation.

Three scenarios are analysed by comparing a farm situation before and after the changes. The scenarios are

1. **"Herbicide taxes"** by increasing herbicide prices by 100%, 200%, 300%

2. **"Goal driven reduction of herbicide use"** by weighting the farmer's objective towards herbicide minimisation in addition to profit maximisation.

3. **"Alternative cultivation systems"** by comparing a farm situation with shallow cultivation instead of ploughing.

Note that herbicide use is constant under a particular farm system whatever the tax rate because the same level of herbicide is needed to achieve constant weed control. This is contrary to fungicide use, where a fungicide tax **would** influence the amount of control which was justified. A farmer would choose to decrease the level of fungicide use and accept the resulting loss in crop yield for each year. Herbicides cannot be considered like this because a decrease this year influences the amount used next year to keep control over the weeds. So although a farmer might save in the short term, in the long-term s/he would have to revert back to the amount of herbicide needed to keep the weeds at a particular level, unless changes to the farming system are made.

RESULTS

Figure 2 summarises the results of scenarios 1 and 2 for typical roots farm on sandy loam soil, assuming a ploughing cultivation system. A selection of these solutions are also shown in Table 2. The resulting cropping for the base scenario is 32% winter wheat, 21% winter barley, 3% potatoes, 13% sugar beet, 5% winter rape, 22% spring beans and 4% setaside. In the model input spring barley was available, however the optimal solution for the base situation does not include this crop. The annual net profit of this profit optimising farm is £455/ha, using doses of herbicide for wild oat and blackgrass control of 45.7 and 6.6 per 100 ha of farmed land respectively.

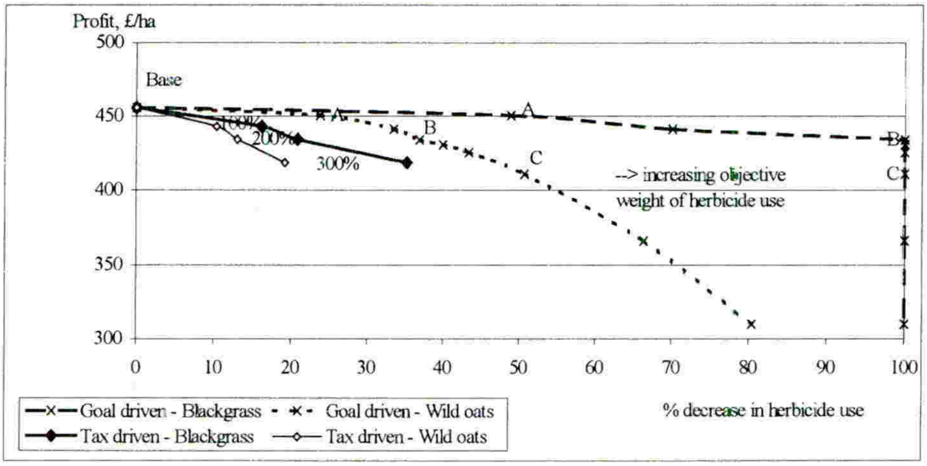

Figure 2 Optimal outputs for a typical sandy loam roots farm under alternative strategies to reduce herbicide use. Labels refer to scenarios in Table 2

The solid lines represent the solution values for increasing both herbicide prices by the amounts indicated against the markers. It is clear that as the herbicide price increases the farmer needs to adjust the cropping and farm systems to optimise the profit and maintain constant weed control. However, even with these adjustments the optimum farm profit declines for a small decrease in herbicide use. For example, at a 200% herbicide price increase, the profit is £434/ha with a decrease in wild oat and blackgrass herbicide use of 10% and 16% respectively.

The dotted lines represent the trend of model solutions (marked by the crosses) where the farmer has an increasing interest in decreasing the amount of herbicide used in addition to maximising profit, but without the increases in herbicide price. In the model, this is achieved by optimising an objective function of the sum of weighted profit and herbicide use. In other words the farmer is willing to sacrifice some profit for a reduction in herbicide use. At the profit of £434/ha, (solution B) the farmer under these conditions can change the farm system and cropping so that wild oat and blackgrass herbicide use decreases by 37% and 100% respectively. The herbicide decreases are obtained by, the farmer increasing the area of break crops, so more first-wheat and barley crops are grown. As the farmer has more interest in reducing herbicide use the optimum farm cropping moves towards growing spring cereal (ie spring barley) which has the advantage of needing less herbicides to control the weeds, although at a lower profit.

Table 2 A selection of solutions showing profit, herbicide use, cropping and % ploughed area

Scenario:-	Base 0% tax	200% tax	Goal A	Goal B	Goal C	Plough only[1]	Cult only[1]	Cult/ plough wheat[1]
Net profit, £/ha	455	434	450	434	411	407	422	419
Wild oat herbicide use, dose/100ha	45.7	39.8	34.8	28.9	22.5	27.2	22.0	23.2
Blackgrass herbicide use, dose/100ha	6.6	5.2	3.3	0	0	5.2	15.6	13.6
Cropping, % area:-								
Winter wheat	32	30	31	31	21	53	51	51
Winter barley	21	18	16	13	12	17	19	19
Spring barley	0	0	0	0	9	0	0	0
Winter rape	5	7	11	14	15	25	25	25
Spring beans	22	25	25	25	25	N/A	N/A	N/A
Potatoes	3	3	4	5	6	N/A	N/A	N/A
Sugar beet	13	12	10	7	7	N/A	N/A	N/A
Setaside	4	4	4	4	4	5	5	5
% area ploughed	N/A	N/A	N/A	N/A	N/A	100	0	50.4

Note 1. These solutions are for a cereal farm on clay soil, all other solutions are for an arable farm on sandy loam soil.

The third scenario, "alternative cultivation techniques", is interesting since there is a perception that farmers can save machinery cost by using non-plough cultivation methods. These different methods also have an implication for weed control and thus herbicide use. Ploughing is a useful way to bury blackgrass seed, which then dies, whereas for wild oats ploughing year after year returns viable seed to the surface where it can germinate. Thus less blackgrass herbicide and more wild oat herbicide is necessary for constant control under ploughing than not turning the soil over as in shallow cultivation. Thus comparing farm systems using the alternative techniques should show these differences in the amounts of the respective herbicides necessary to maintain level control. The farm modelled is a cereal farm on clay soil. Under the conditions of profit optimisation only, using ploughing effects a net annual profit of £407/ha, using 27.2 and 5.2 doses per 100ha of wild oat and blackgrass herbicide respectively, whereas shallow cultivation effects a profit of £422/ha and herbicide doses per 100ha of 22.0 and 15.6. Thus although there is little difference in profit ploughing helps blackgrass control thus decreasing the need for herbicide, whereas shallow cultivation has positive effect on wild oat control.

Introducing the choice in the model of ploughing or shallow cultivation of winter wheat (all other crops are ploughed) leads to a profit of £419/ha and wild oat and blackgrass herbicide doses per 100ha of 23.2 and 13.6 respectively. The model chooses to shallow cultivate 98% of the winter wheat. Once again by altering the farm objectives to reduce herbicide use as well maximise profit, a reduction in the amounts of both herbicides used is affected by changing the cropping and systems. For example, by increasing the amount of spring cereals instead of winter cereals, ploughing for the first winter wheat after a break crop and shallow cultivating the second wheat. At a profit of £403/ha (a 4% decrease) the wild oat and blackgrass herbicide uses are reduced by 5% and 68% respectively.

CONCLUSION

The Silsoe Whole Farm Model evaluates the profitability and environmental outcomes of farm systems by comparing optimum solutions under different criteria. This paper shows some results of evaluating herbicide use for cereal weed control under three scenarios of herbicide taxes, goal driven reduction and using alternative cultivation systems. The study shows that goal driven herbicide reduction reduces herbicide use by more than twice as much as a herbicide tax for the same loss in farm profit. For a 5% loss in net profit, the farmer can achieve herbicide reductions of 37% and 100% for wild oat and blackgrass herbicides respectively, whereas a 200% herbicide price increase reduces profit by the same amount resulting in herbicide decreases of only 10% and 16%.

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