HGCA

PROJECT REPORT No. 107

COST-EFFECTIVE WEED CONTROL IN CEREALS:

PART I. COMPETITION, POPULATION DYNAMICS AND BASIC HERBICIDE RESPONSE STUDIES;

PART II. FIELD TRIALS AND SEEDBANK STUDIES

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COST-EFFECTIVE WEED CONTROL IN CEREALS: PART I. COMPETITION, POPULATION DYNAMICS AND BASIC HERBICIDE RESPONSE STUDIES; PART II. FIELD TRIALS AND SEEDBANK STUDIES

by

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1.1 Executive Summary

1.1.1 INTRODUCTION

This report must start by emphasising the collaborative nature of the work. For many years through a good liaison network a small number of weed specialists have conducted collaborative studies on several occasions. The HGCA support allowed the development of this program integrating basic biological understanding of weed competition and reproductive strategies with the practical evaluation and testing of cost-effective approaches to weed control.

1.1.1.1 Herbicide Usage and the Need for Change

Surveys by MAFF show a high level of herbicide use. In 1990, 98.5 % of all winter cereal crops, 95.6 % of spring barley crops and 93.2 % of oat crops were treated. The average or "National" wheat crop was treated more than twice, with 2.6 active ingredients. These figures were little different from surveys done in 1982, 1988 and 1990. The two most widely used herbicides, isoproturon and mecoprop were each used on over 1.5 million hectares in 1990 mostly on 2.7 million hectares of winter cereals, although there was some use of mecoprop in spring crops.

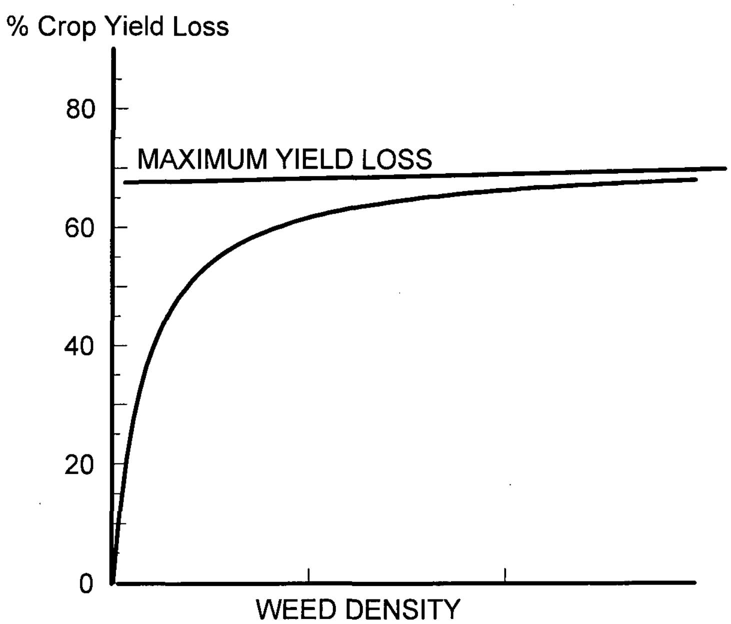
By 1987 it was apparent that there was need to explore methods to reduce this use of herbicide, for economic reasons and in response to pressures from the environmental protection movement. The European Community had drafted a Directive on water quality which imposed rigorous limits on the level of pesticide permitted in potential supplies of potable water. The UK Food and Environmental Protection Act (1985) required all farmers to make use of "thresholds" in making crop protection decisions.

For all these reasons, a group of research workers with a record of earlier collaborative work approached HGCA for funding to supplement the work funded by MAFF, DAFS (SOAFD) and DANI on the project described here.

1.1.1.2 Predictive Approaches to Weed Control

Earlier work (Cousens, 1985) had shown that the relationship between density of a single weed species and a crop could usually be described by a hyperbolic curve (Fig.1.1.1). In practical terms this relationship indicates that each weed has a similar effect at very low densities but, as the weed population increases, there is increasing competition between the weeds as well as between weeds and crop until a maximum effect is reached.

Figure 1.1.1 Basic crop / weed density relationships between percentage yield loss and weed density



A further complication is the site to site variation in response, so that although the general form of the response curve remains constant, a given density of weeds may have twice the effect on some sites as on others. Crop density has a very powerful effect as does the relative time of emergence of crop and weed seedlings - early germinating weeds have much more effect on crop yield than late germinators. Some elements of this site to site variability had not been explored before the start of this program.

It was also clear that the seeds produced by weed populations which remained untreated would persist in the soil to create potential economic effects later in the cropping cycle and some longer term thresholds had been calculated for a small number of grass weeds (Cousens *et al.*, 1986; Cussans *et al.*, 1986; Doyle *et al.*, 1986). There was little or no information available which would allow us to estimate long-term economics of control of broad-leaved weeds.

One additional problem with prescribing weed control thresholds was that most studies of weed/crop competition had been done with simple mixtures of one weed species and one crop species. This is reasonable for grass weeds where very often spray/no spray decisions are made on the basis of a single species. However, we envisaged the greatest scope for economy in the control of the less competitive broad-leaved weeds and, with these, decisions usually have to be made on the basis of a mixture of at least six weed species. There was no firm basis on which to proceed but a working hypothesis had been devised at the former Weed Research Organisation based on assessments of dry matter growth of a range of weed species. This had led to the theory of Crop Equivalents (C.E.), based on the size that different weed species grow relative to the crop and envisaging competition as being a replacement of crop by weed biomass. This theory although known to be marginal for some weeds, provided a reasonable practicable prospect of estimating the effects of mixed weed populations (Cussans *et al.*, 1987).

The Crop Equivalent (C.E.) system had been used as a guide for treatment but not an absolute rule during the Boxworth project. Apart from that, it had received no practical evaluation in the field. The decision threshold adopted to determine herbicide application was that of a total 5 C.E.s per m^2 which, in a 250 winter wheat plants per m^2 crop, would give a target 2% reduction in yield.

1.1.1.3 The Potential for Reduced Rate Strategies

Manufacturers' recommended doses of many herbicides tend to be conservative. A dose is recommended which will ensure adequate performance over a wide range of weed growth stages and environmental conditions. In many cases the dose can be reduced with very little diminution of effect, although it has to be accepted that lower doses result in at least an increased risk of impaired performance. Many farmers are reluctant to accept any risk but the gamble on reduced performance may be well worth while, particularly where major grass weeds, notably Black-grass and wild oat, are not a major problem. There was, however, a need to test this arbitrary use of a reduced rate option in comparison with the more defined adoption of a non-spray threshold. For both options economic performance and longer term effects on weed seed dynamics had to be established.

Overall, by 1987 the theoretical framework for advice on reduction in herbicide use was very largely in place. There was, however, a need for much more information to improve our ability to predict the outcome of weed competition and to test the models which were available. There was also a need to relate long-term and short term economics of weed control by study of long-term population changes in response to treatment regime. Finally, there was a very real need to explore the practical use of systems designed to reduce expenditure on weed control and the basis of herbicide response in relation to crop and weed density interactions.

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1.1.2 SUMMARY CONCLUSIONS

1.1.2.1 Competition and Population Dynamics

Much new information was gained on the relative competitive abilities of a range of broad-leaved and grass weeds. Some of the factors leading to variation in response were studied and quantified for the first time. Our ability to predict the outcome of crop/weed competition is much improved as a result of this program (although it is still relatively imprecise). The effects of crop density, relative time of emergence and soil nutrient level have been examined for a number of weed species. The phenology of growth of a number of weed species has been studied.

For the first time, seed production of some of our major broad-leaved species has been measured and related to total dry matter production. Behaviour of these seeds in the soil has also been recorded, revealing some surprising differences in seed persistence between species. Simple models of long-term behaviour of these weeds have been derived; the first step in quantifying the relationships between short term and long-term economics of weed control. These specific studies have been supplemented by study of soil seed bank populations from the long-term systems experiments described below.

The basic information gathered on herbicide efficacy and dose response relationships remains central to the adoption of herbicide programs which are appropriate and not in excess of requirements, thus improving cost effectiveness and reducing potential phytotoxicity.

1.1.2.2 Farming Systems

The work on systems of weed control in practice has shown that the arbitrary thresholds used were conservative, erring on the side of "spray" rather than "no spray" decisions. However, because weed populations were usually above threshold levels, savings were modest and the work involved in assessing the weeds may not have been recouped by an economic benefit. In contrast, half doses of herbicide "Insurance treatments " appear to have worked as well as full doses on almost all sites, giving maximum economic benefit for little sacrifice of yield or cost in management time.

1.1.2.3 The Future

The initial program has been supplemented by further funding on Appropriate Rate Herbicides for Cereals (HGCA Project 0049/2/91) and related reduced rate studies in Scotland. These are providing additional practical and basic information on specific weeds and herbicides to develop the cost effective strategies initiated in this program. This initial program can be seen to have contributed significantly to a new appreciation and awareness of cost effective and environmentally friendly weed control within the farming community and the agrochemicals industry.

1.2 PART 1 SUMMARY:

COMPETITION, POPULATION DYNAMICS AND BASIC HERBICIDE RESPONSE STUDIES.

RESEARCH OUTLINE

Research conducted mainly at LARS with collaboration from SCRI and QUB.

This section comprises the basic biological studies designed to establish the competitive ability and seed production and persistence of individual weed species in winter wheat and spring barley and their response to crop density and fertility level. Also considered are the significance and basis of site and seasonal variation of competitive ability reflected in the Crop Equivalent (C.E.) values.

In addition it includes studies on the significance of crop and weed density on the performance of herbicides.

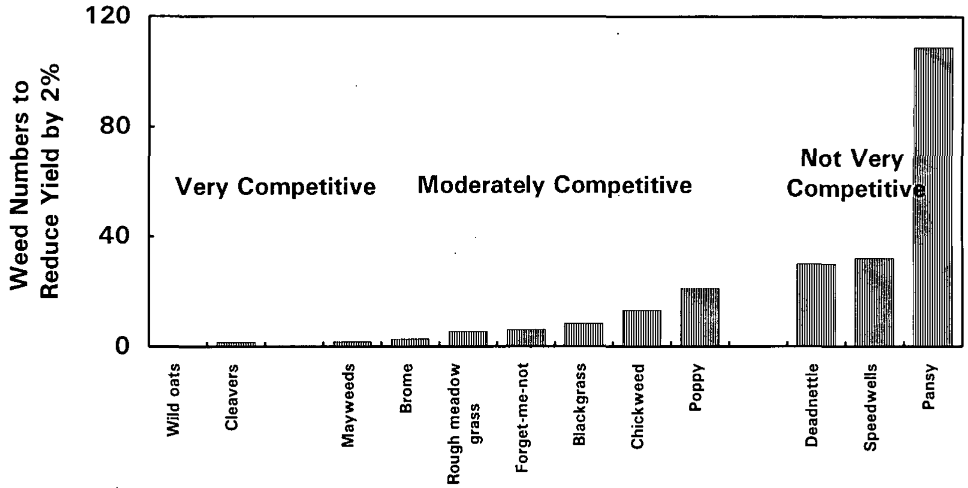
1.2.1 COMPETITION STUDIES

1.2.1.1 Winter Wheat Species Comparison

Competition and effects on yield demonstrated a distinction between early species (speedwell, red dead-nettle and chickweed) which had little effect on crop yield, compared to cleavers, wild oat, black-grass, rough stalked meadow-grass, field pansy, forget-me-not, poppy and mayweed which flowered later, continued growth throughout the season and were more competitive, often resulting in substantial yield losses.

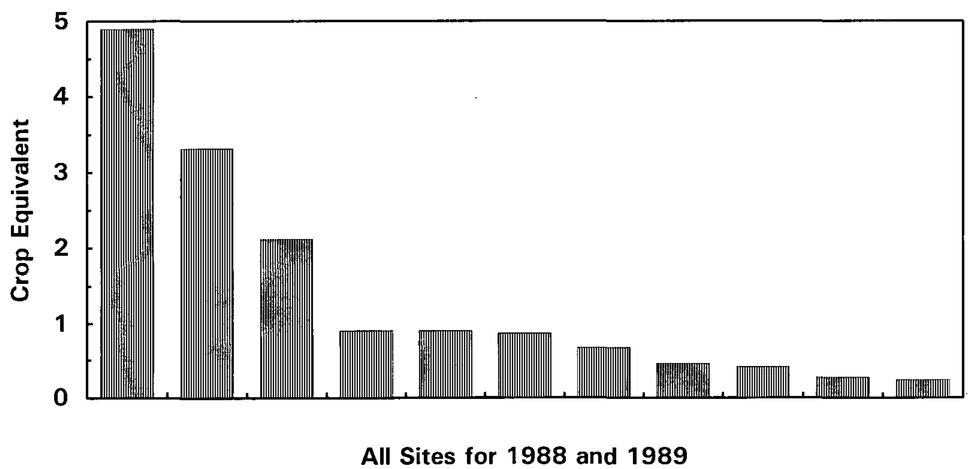
This ranking order (Figure 1.2.1) has proved valuable for consultants, advisors and farmers for recognising wild oat and cleavers as the most competitive species which must be controlled to preserve yield, and the less competitive species where savings in control costs may be possible. Climatic and crop factors may influence the levels of response as demonstrated in the seasonal and site variation in C.E. values.

Figure 1.2.1 Competitive ranking of weeds in winter wheat: Long Ashton data



The series of experiments at sites throughout the UK provided an ideal opportunity to assess the order of variation in C.E. values between sites and years and the results for cleavers (Figure 1.2.2) allow this to be appreciated.

Figure 1.2.2 Variation in Crop Equivalent values for Cleavers 1988 and 1989



C.E. values (Figure 1.2.2) ranged from 0.24-3.32 in 1988 and 0.42-4.90 in 1989 for the largest peak in June, and these are within the range observed by Wilson & Wright (1987). These data, because of the geographic spread and diversity of site factors, indicate the range of weed development which has to be accommodated in predicting weed competition based on C.E. values. Of the individual site factors emergence date of the weeds relative to the crop of key importance. In winter wheat this factor alone could account for a three-fold difference in C.E. values in cleavers.

Despite this, the competitive ranking order (Figure 1.2.1) seems fairly consistent and predictable from year to year.

1.2.1.2 Spring Barley

Using a similar approach as for wheat, the relative competitiveness of different weed species in spring barley was studied in experiments at LARS and QUB. Charlock, cleavers, wild oat and corn marigold were the most competitive species.

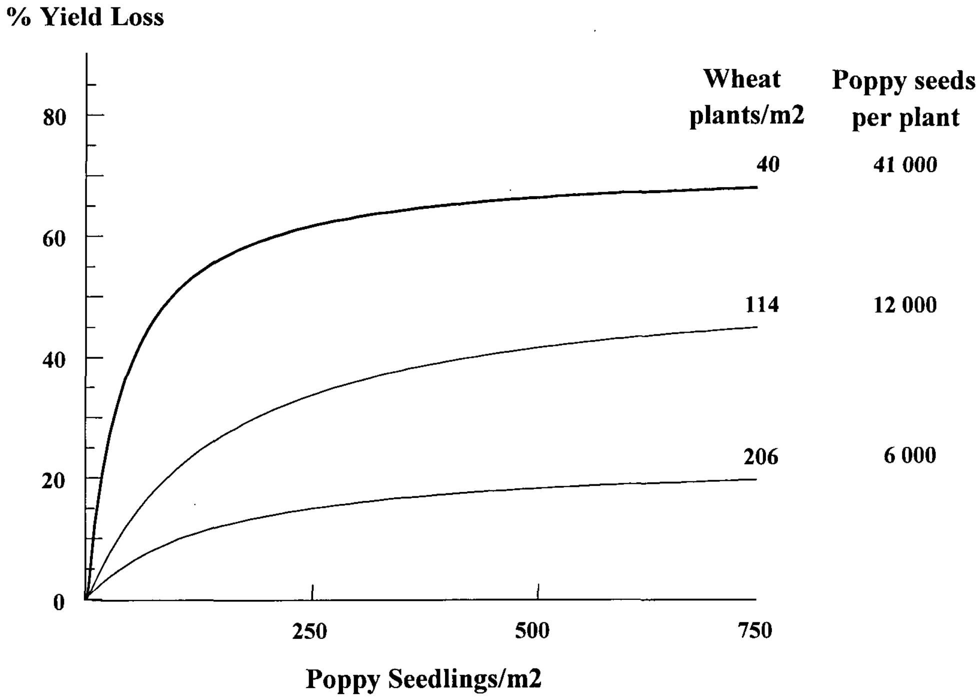
1.2.1.3 Effect of Crop Density on Weed Competition

Weed growth and wheat yield response were strongly influenced by crop competition as illustrated in Figure 1.2.3 where poppy competition was recorded at a range of winter wheat densities. Yield loss from poppy approximately doubled as crop density was halved. On the basis of an 'acceptable' yield loss of 2%, the response curves showed that, in this experiment, we could tolerate 9 poppy plants/m^2 in a 'normal' crop density, 6 plants/m^2 when crop density was halved and only 1-2 plants/m^2 in the thin crop of 40 wheat plants/m^2. This indicates the extent to which weed thresholds would need to be lowered in thin and poorly established crops. The C.E. model has the advantage of making this allowance for crop density.

1.2.1.4 Effect of N Level on Weed Competition

Cleavers and wild oat responded more to nitrogen than wheat. This work suggests that, in competitive situations with these weed species, reductions in nitrogen fertiliser will benefit the crop relatively more than the weeds.

Figure 1.2.3 The effect of crop density on yield loss and poppy seed production



1.2.2 WEED POPULATION DYNAMICS

Work on population dynamics is prompted by the need to forecast changes in weed populations in response to reducing use of herbicides, in particular the potential build up of weeds from uncontrolled populations at densities which would be below thresholds. Studies of the production of weed seeds, and the persistence of weed seeds in the soil have been carried out at Long Ashton in conjunction with the Scottish Crop Research Institute.

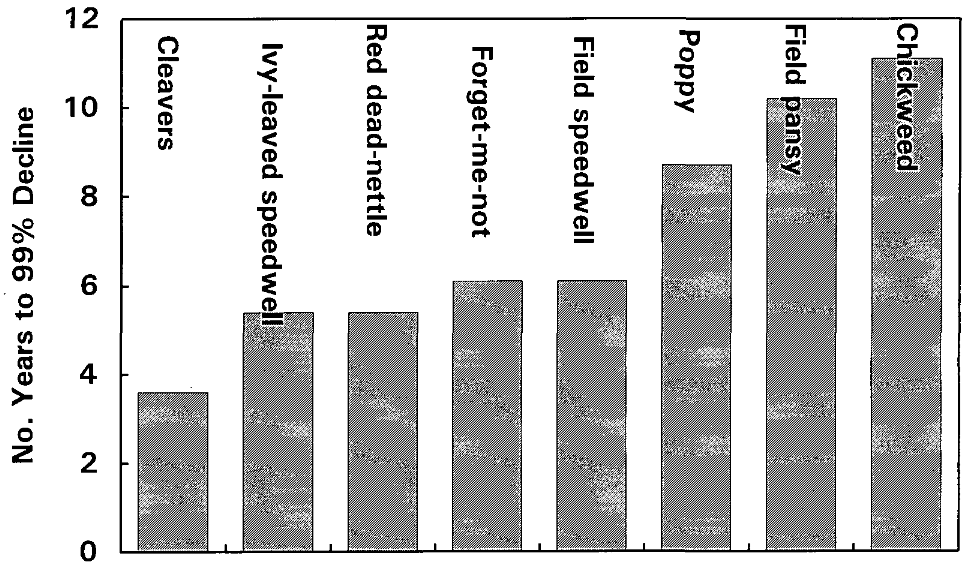
As illustrated in Figure 1.2.3 the crop had a strong influence in limiting weed seed production. At the lowest crop density, poppy was the most prolific species with over 40,000 seeds per plant in 1988. A nitrogen rate of 200 kg/ha produced a three fold increase in seed production of wild oat and cleavers in 1990 and almost double in 1991 compared with zero nitrogen.

Data from the spring barley competition studies at QUB showed good relationships between weed biomass and seed output.

1.2.2.1 Seed Persistence Studies

Studies of weed seed production are basic to further investigations of the losses of weed seeds, their persistence in the soil and the emergence of weed populations in subsequent crops.

Figure 1.2.4 The estimated time to 99% decline of selected weeds in winter wheat



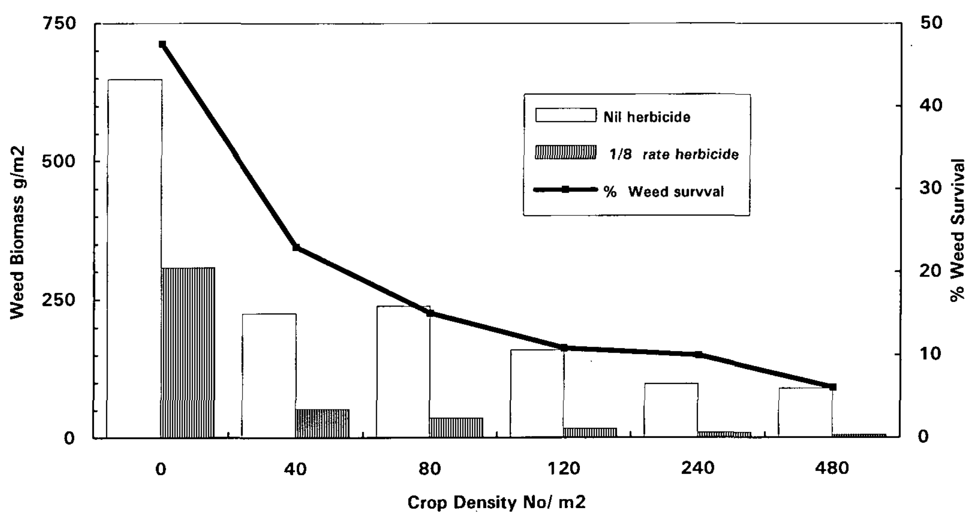
Seedbanks and the emergence of weed seedlings, resulting from seeds shed in wheat crops and ploughed in, were monitored in two experiments between 1987 and 1990, in successive autumn sown crops. The persistence (estimated time to 99% decline) is illustrated in Figure 1.2.4. This ranged from 3.6 years for cleavers to 11.1 years for chickweed. It was concluded from this work that poor weed control in one year could result in substantial addition to the seedbank for up to four years, and much longer in some cases. Total weeds of all species which emerged over the 3-4 years represented only a very small proportion (between 3 and 4%) of the first year seedbank.

1.2.3 STUDIES TO INVESTIGATE THE BASIS OF HERBICIDE RESPONSE IN CEREALS

1.2.3.1 Effect of Crop Density on Herbicide Efficacy

Figure 1.2.5 The Influence of Crop Density on Herbicide Performance in Winter Wheat:

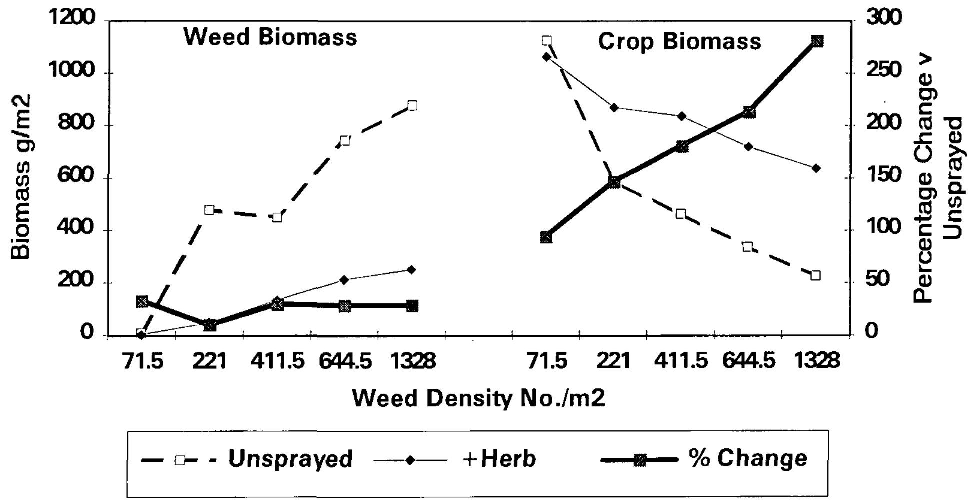
N. Ireland data 1/8 Rate (DFF/IPU: metsulfuron-methyl sequence)



These data from a winter wheat experiment in N. Ireland (Figure 1.2.5) demonstrate that the reduction of crop stand and competition reduced herbicide efficacy. In this instance the efficacy of an 1/8th rate of a herbicide sequence reduced from 95% control at the highest density to 50% in the absence of a crop. With reduced herbicide rates, particularly at low crop densities, deficient control can also result in the replacement of susceptible by more tolerant species. A longer term problem may then occur and clearly any reduced rate regime has to control of the most tolerant species present.

1.2.3.2 Effect of Weed Density on Herbicide Efficacy

Figure 1.2.6 The effect of weed density (oilseed rape) on herbicide efficacy and crop response in spring barley



Herbicide efficacy, expressed as percentage weed control, remained constant at all weed densities. This has been confirmed by preliminary modelling of the data at Long Ashton Research Station which failed to show any interaction between weed density and herbicide efficacy at any of the rates of herbicides tested (Brain pers. comm.).

The yield response, in absolute terms, biomass increase and percentage change relative to the control, increased with increasing weed density. At the higher weed densities the crop failed to compensate fully for removal of the weed and both biomass and yield (not presented) declined as weed density increased. This may be attributed to the higher residual weed biomass at the higher oilseed rape densities.

Data from an experiment comparing the relationship between biomass and seed production indicated that, in oilseed rape, seed production was about 4 times as sensitive to herbicide as was biomass. If this applies in a similar way to weed species then except where very tolerant weeds occur, a reduced rate herbicide regime should not encourage a longer term increase in the seed bank.

1.2.4 CONCLUSIONS

The trials confirmed the basis for predictive approaches to weed competition and the roles of crop density and fertility level on competition and weed seed production in cereal crops.

They also indicated the need for further information on site to site variation in weed / crop interactions if C.E. values or another predictive parameter is to be used to determine weed control strategies.

The seed persistence and seedling emergence data also contributes to the implementation of effective long-term strategies for weed control.

The basic herbicide information identified the key importance of crop competition and the way it can be used to complement weed control programs with the most effective use of herbicides.

1.3 PART II SUMMARY

FIELD TRIALS AND SEEDBANK STUDIES

1.3.1 PROGRAM OUTLINE

A trial series on cereal-based rotations was established at five sites in England, four in Scotland and one in N. Ireland in the 1987/88 season. At these sites, over a four year period, the short and long-term effects of weed management systems based on the use of weed thresholds were compared with routine full and half-rate use of appropriate herbicides. Sites in Scotland and N. Ireland also had a no herbicide use treatment, and at the four Scottish sites, treatments were also included +/- pre-harvest use of glyphosate (Roundup). This latter treatment was designed to examine the impact of weeds at harvest, and whether pre-harvest glyphosate was effective in removing problems associated with leaving weeds at threshold levels.

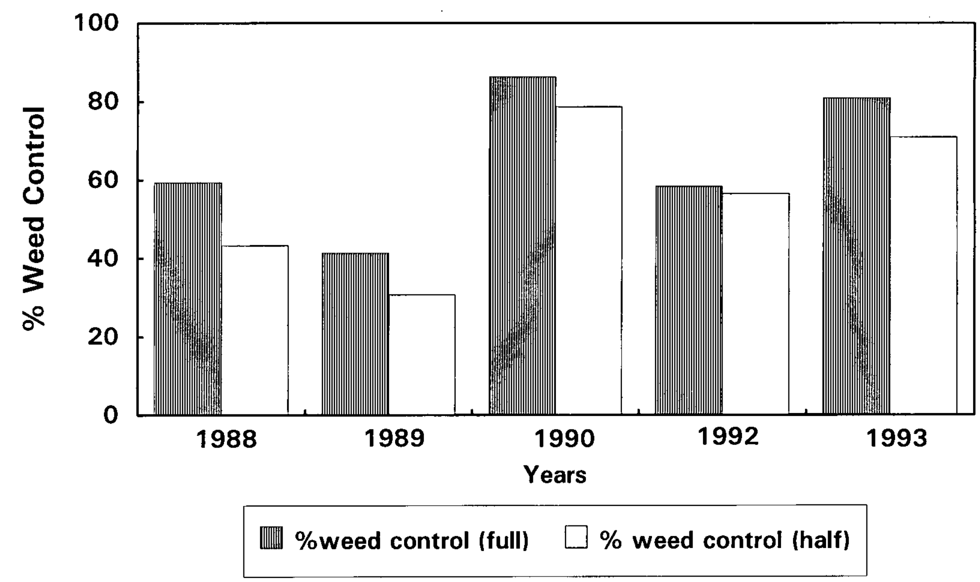
1.3.2 THE USE OF THRESHOLDS

Treatment weed thresholds (normally 5 C.E./m^2) were exceeded on most spray occasions at most sites, up to 84% in year four, despite the sites having been selected as not being particularly weedy. It is therefore likely that, in practice, few cereal fields would have below threshold levels of weeds. The actual recording of threshold levels was very time consuming. There is a need for a simpler technique for farmers and further consideration of the threshold levels. There is now a move to utilise thresholds as an indicator for a reduced rate rather than a nil use of herbicide, although this could still be valid in some situations.

1.3.3 WEED CONTROL

There was little difference between full and half-rate herbicide treatments in the levels of weed control achieved. This can be seen in the N. Ireland data where the use of half-rates produced weed control about 5% lower than the full-rate. The main differences occurred in a dry autumn, and as population levels became high in threshold option plots.

Figure 1.3.1 The effect of herbicide rate on percentage weed control: N. Ireland data meaned over herbicide regimes



1.3.4 YIELD RESPONSE

Figure 1.3.2 shows that there was little difference in yield response between treatments in winter wheat or in spring barley. In the sites (Scotland and N. Ireland) where untreated plots were included, it was only in years three and four that weed levels started to clearly reduce yields (Figure 1.3.3).

Figure 1.3.2 Effect of herbicide rates on yields of winter wheat

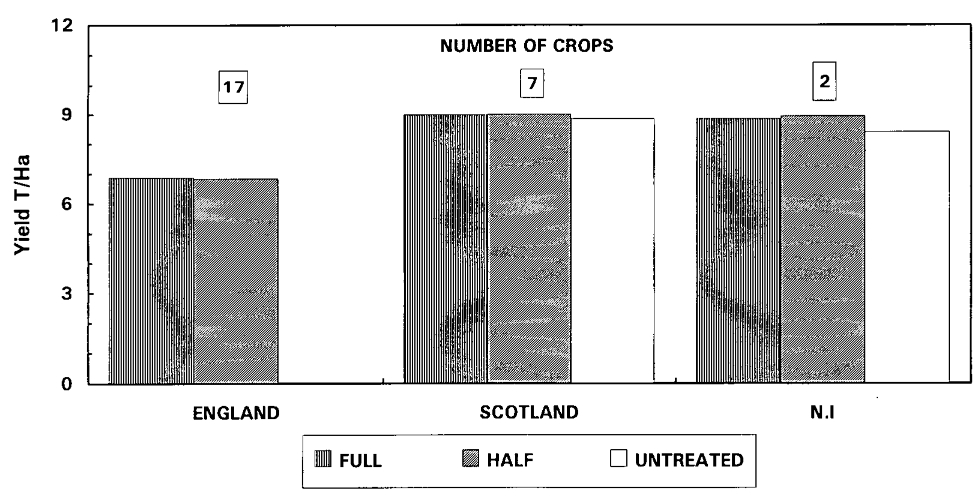
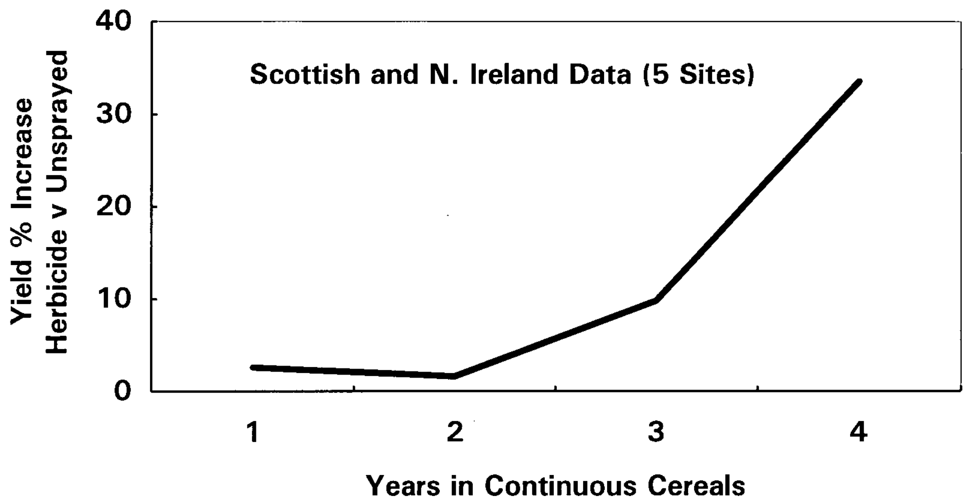


Figure 1.3.3 The yield response to herbicide compared to the untreated control



At one site, with three seasons of winter barley, yields were reduced because of a chickweed build-up after use of the first threshold option.

At other sites reductions in weed control from the half-rate application were not reflected in reduced yields, in the first four years, but there was possibly a trend to lower yields where only a half-rate of herbicide was used to clear up weeds after plots had exceeded the threshold levels.

1.3.5 PRE-HARVEST DESICCATION

Use of glyphosate pre-harvest usually improved matter other than grain (MOG) throughput in weedy plots, so improving combine speed and reducing grain losses. There was an occasional improvement in grain dry matter. However, the build-up of weed seeds in the otherwise unsprayed plots was also delayed and it is unlikely that these advantages would be more cost-effective than using earlier herbicide treatments.

1.3.6 COST-EFFECTIVENESS

Although at the Scottish and N. Ireland sites nil herbicide use was cost-effective during the initial 2-3 years of the trials, this then led to a rapid build-up of weeds and subsequent yield loss and overall the most cost-effective option was the routine half-rate insurance treatment. Threshold options proved costly to assess, and these plots usually required herbicide treatment (Table 1.3.1).

Table 1.3.1 Average margin of improvement (£/ha) over herbicide costs (MOHC) per site relative to MOHC for full-rate full insurance treatment; winter wheat (17 sites)

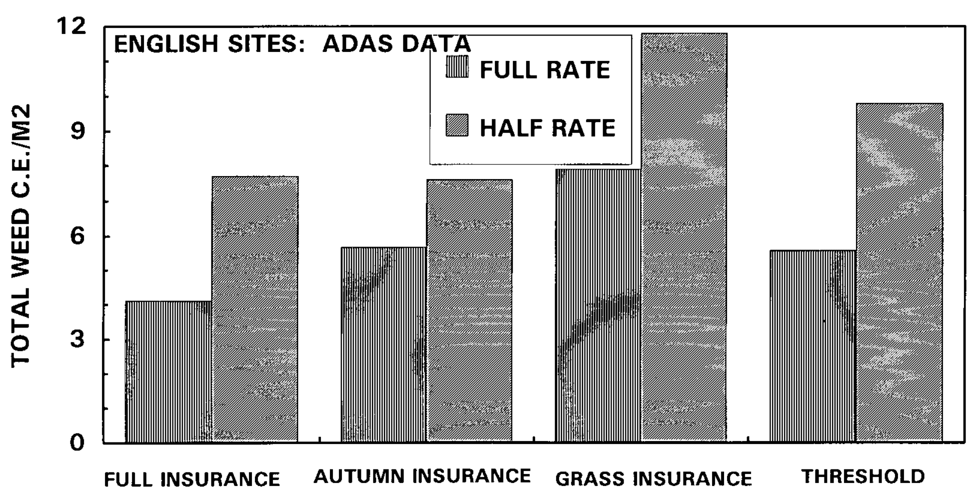
Treatment	Full-rate	Half-rate
Insurance	0	+67
Threshold	+24	+92

1.3.7 LONG-TERM WEED POPULATION CHANGES

1.3.7.1 Seedbed Seedling Levels

The indications of potential long-term changes in the weed populations were obvious in the untreated plots in Scotland and N. Ireland where populations increased rapidly in years three and four. The potential response to the herbicide regimes tested is illustrated by the English sites where the use of half-rates increased weed levels (C.E./m^2) relative to the full-rates and the routine use of a full insurance treatment (broad spectrum herbicide applied in both autumn and spring) gave the lowest weed levels in year four.

Figure 1.3.4 The effect of herbicide regime on weed levels (C.E./m^2) in year four



The other herbicide regimes represented in Figure 1.3.4 are autumn treatments designed to give control of either, both broad-leaved and grass weeds (autumn insurance), or grass weeds only (grass insurance), with threshold decisions taken in the spring.

1.3.7.2 Seedbank Change

Table 1.3.2 shows that seedbank numbers also reflected the better performance of the full insurance treatments than any of the other options tested in keeping populations low. It was also clear that half-rate treatments consistently resulted in higher seedbank populations than the full-rate treatments, although differences were not always statistically significant. However, all treatments very effectively prevented the explosion in seedbank numbers that resulted from four years without any herbicide treatment.

Table 1.3.2 Seedbank numbers after 4 crops

SEED NUMBERS (1,000s per m^2 to 20 cm)

REGIME	DOSE	ADAS/NI	SAC
FULL INSURANCE	FULL	3.2	2.1
	HALF	4.1	2.3
AUTUMN INSURANCE	FULL	4.3	-
	HALF	5.9	-
GRASS INSURANCE	FULL	4.2	-
	HALF	5.2	-
THRESHOLD	FULL	3.5	3.0
	HALF	4.4	4.3
UNTREATED			18.5

1.3.8 CONCLUSIONS

Although the basic relationship between weed numbers and yield penalty was clearly demonstrated on the untreated plots, the use of thresholds proved difficult in practice. There was identified a need for a simpler method of assessment with decisions based on thresholds used to determine an appropriate rate strategy of herbicide usage.

The use of glyphosate pre-harvest did aid harvesting where spray thresholds had not been exceeded but excessive weed growth occurred. A reduced rate herbicide would normally be more cost-effective.

Half-rates of insurance herbicides in general gave effective weed control and provided the most cost-effective management strategy.

The longer-term monitoring of the seedbed seedling numbers and seedbank changes suggested that where half-rate herbicides had been applied weed levels were slightly higher in year four, especially in threshold option plots.

In any reduced herbicide regime farmers would need to avoid situations where problem weeds occurred or when obvious soil or weather factors were likely to reduce herbicide activity.

Where a sudden increase in weed numbers occurred, then higher rates might occasionally be required to maintain control.

COST-EFFECTIVE WEED CONTROL FINAL REPORT

2.1 OBJECTIVES

1. To test and refine a system for predicting the effects of weed competition and to determine the effects of major variable factors on the crop/weed balance.

2. To test weed management systems in practice. To estimate the costs of monitoring weed populations and the potential savings in herbicide use in "managed systems".

3. To study the seed population dynamics of important broad-leaved weeds.

PART 1

COMPETITION, POPULATION DYNAMICS AND HERBICIDE RESPONSE STUDIES

3.1 STUDIES OF WEED COMPETITION

The program at Long Ashton concentrated on weeds in winter wheat, with the aim to improve prediction of the competitive effects of weeds as a basis for advice in reduced input systems. The concept of C.E.s, as indices of competition for different species, was introduced during earlier work at the Weed Research Organisation. At that time experiments were carried out with mixed weed species infestations on farms, which made species comparisons difficult, with a lot of site to site variation.

3.1.1 COMPETITION IN WINTER WHEAT

3.1.1.1 Species Comparison

Two experiments, partly funded by HGCA, were carried out at Long Ashton in 1987 and 1988, to compare the competitive effects of a range of annual weed species in wheat.

Table 3.1.1 Month of flowering, weed weight (maximum and at harvest) and wheat yield loss, 1988

Weed Species	Onset of flowering	Maximum weed wt. attained	Weed wt. at harvest g/m^2	Estimated % yield loss at high weed density
EARLY WEEDS				
Field speedwell	February	May	19	7
Ivy-leaved speedwell	February	May	1	6
Red dead-nettle	February	May	9	7
Chickweed	February	May	53	10
LATE WEEDS				
Black-grass	April	June	314	53
Rough-stalked meadow-grass	April	June	269	47
Field pansy	May	July	92	25
Forget-me-not	May	July	135	21
Poppy	May	July	103	44
Wild oat	June	July	985	100
Cleavers	June	July	520	99
Mayweed	July	July	122	16

Weeds were established by hand sowing of weed seeds prior to drilling. Twelve species, each grown separately, were compared in terms of weed growth patterns and effects on crop yield.

Early species (Table 3.1.1) were identified as speedwell spp., red dead-nettle and chickweed which flowered from February onwards, made growth early in the season and died away by crop harvest. These had little effect on crop yield, the crop having time to compensate for early weed competition. In contrast, cleavers, wild oat, black-grass, rough-stalked meadow-grass, field pansy, forget-me-not, poppy, and mayweed flowered later, continued growth throughout the season and were more competitive, often resulting in substantial yield losses. Wild oat and cleavers were very competitive, almost eliminating the crop at high density.

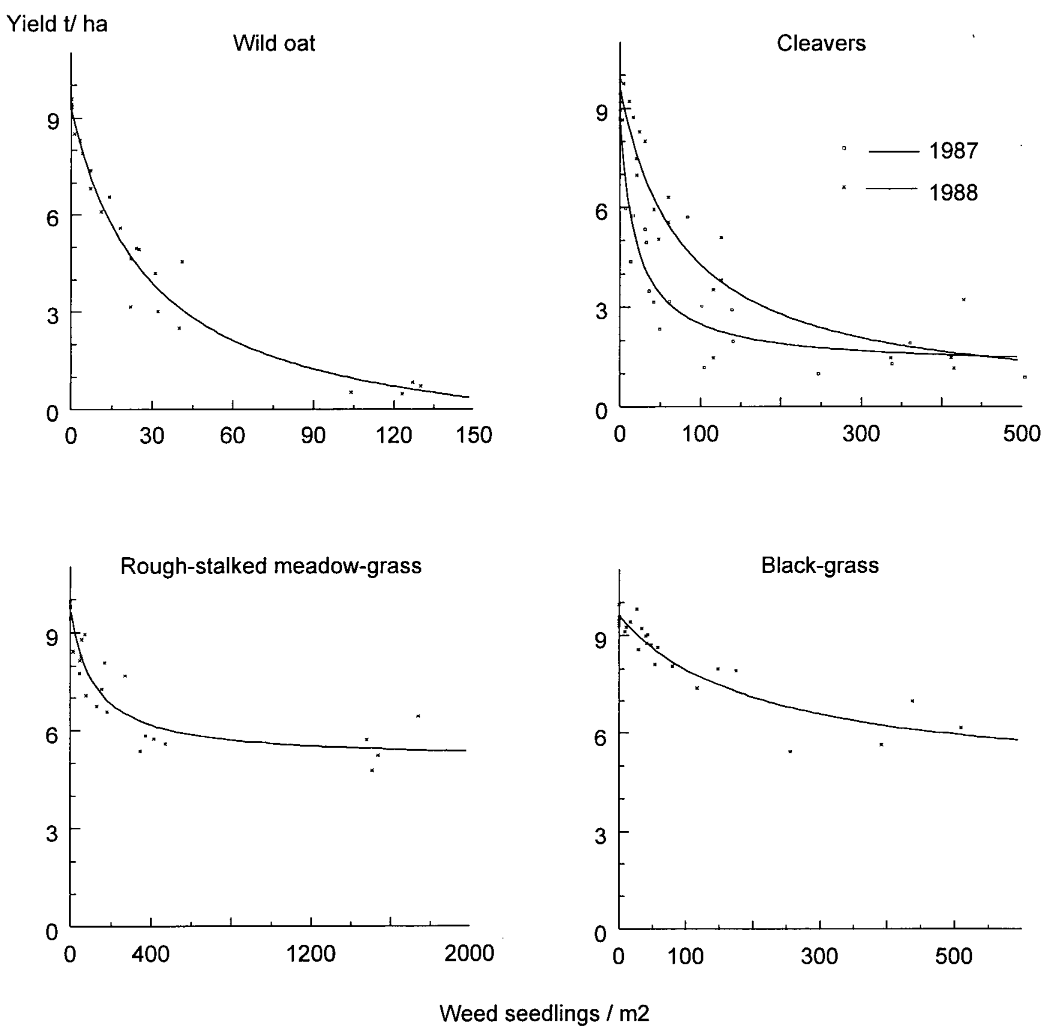
C.E. values (Table 3.1.2) were obtained for each species from the weights of individual weed and crop plants (in the absence of weeds), when the weeds had reached maximum weight. C.E. values have been used as the basis for herbicide decisions for the series of HGCA funded long-term threshold experiments carried out by ADAS, SAC and DANI. The use and limitations of C.E.s for forecasting yield losses has been discussed (Wilson and Wright, 1990).

Table 3.1.2 C.E. values, derived from 1987, 1988 and from earlier experiments, which have been used by ADAS as a basis for threshold decisions

Weed Species	C.E.
Cleavers	7.2
Wild oats	2.5
Poppy	0.6
Mayweed	0.6
Black-grass	0.5
Rough meadow-grass	0.5
Common chickweed	0.5
Common speedwell	0.5
Red dead-nettle	0.3
Ivy-leaved speedwell	0.3
Forget-me-not	0.2
Field pansy	0.1

Hand sowing of weed seeds enabled a wide range of weed densities to be established within the cereal crop, from which hyperbolic crop yield/weed density response curves were derived (Figure 3.1.1). These response curves allowed comparison of species on the basis of yield loss per weed per m^2 as an index of competition. From these curves we have been able to define weed densities that result in only small yield losses that are not economic to control with herbicides. At present we regard numbers of weeds /m^2 resulting in a 2% yield loss as an 'acceptable yield threshold' at the current economics of herbicide costs and grain prices.

Figure 3.1.1 Weed density yield response curves for wild oat, cleavers, black-grass and rough-stalked meadow-grass



This work has enabled weed species to be ranked in order of competitiveness (Table 3.1.3). Wild oat and cleavers are the most competitive species which must be controlled to preserve yield, and species such as speedwell and red dead-nettle are the least competitive where savings in control costs may be possible. Intermediate in the order are the bromes, black-grass, rough-stalked meadow-grass, mayweeds, forget-me-not, chickweed, and poppy. Climatic factors have resulted in wild oat and cleavers changing places as the most competitive, the former having been favoured by mild winters and the latter having been restricted competitively by dry summers; despite this the competitive ranking order seems fairly consistent and predictable from year to year.

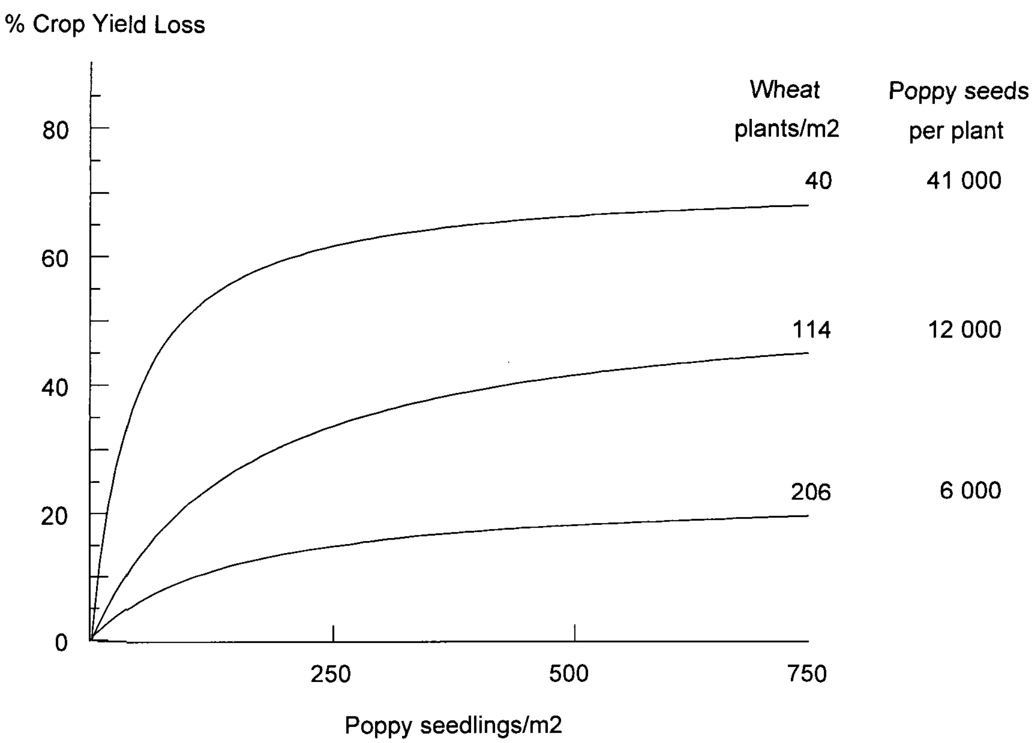
Table 3.1.3 Competitive ranking order of weeds, and threshold numbers/m^2 reducing wheat yield by 2% (predicted from 1988 response curves)

Very competitive	Wild oats	0.5
	Cleavers	1.6
Moderately competitive	Mayweeds	1.7
	Brome	2.7
	Rough meadow - grass	5.4
	Forget-me-not	6.0
	Black-grass	8.3
	Chickweed	13.0
	Poppy	21.0
Not very competitive	red dead-nettle	30.0
	Speedwells	32.0
	Pansy	109.0

3.1.1.2 Effect of Crop Density on Weed Competition

For general advice, it is more difficult to forecast the absolute effect of competition. Many factors vary between sites and between seasons to affect the extent of yield losses from weeds, and there is a need to quantify such variability to improve the reliability of forecasting. One such variable is the density of the crop. In two further experiments carried out at Long Ashton in 1988 and 1989, the influence of wheat density on the competitiveness of red dead-nettle, field pansy and poppy was studied. Weed growth and wheat yield response were strongly influenced by crop competition (Figure 3.1.2). The lowest density of 40 wheat plants/m^2 was surprisingly competitive in restricting weed growth and seed production, compared with weeds grown in the absence of crop. Higher crop densities of 114 and 206 wheat plants/m^2 further limited weed growth and competitiveness. Crop yield/weed density relationships at these three crop densities were obtained for each species. Data for % yield loss per weed/m^2 show that the largest responses were obtained with the more strongly competing poppy; responses were less clearly defined for speedwell and dead-nettle. Yield loss from poppy approximately doubled as crop density was halved. On the basis of an 'acceptable' yield loss of 2%, the response curves showed that, in this experiment, we could tolerate 9 poppy plants/m^2 in a 'normal' crop density, 6 plants/m^2 when crop density was halved and only 1-2 plants/m^2 in the thin crop of 40 wheat plants/m^2. This indicates the extent to which weed thresholds would need to be lowered in thin and poorly established crops.

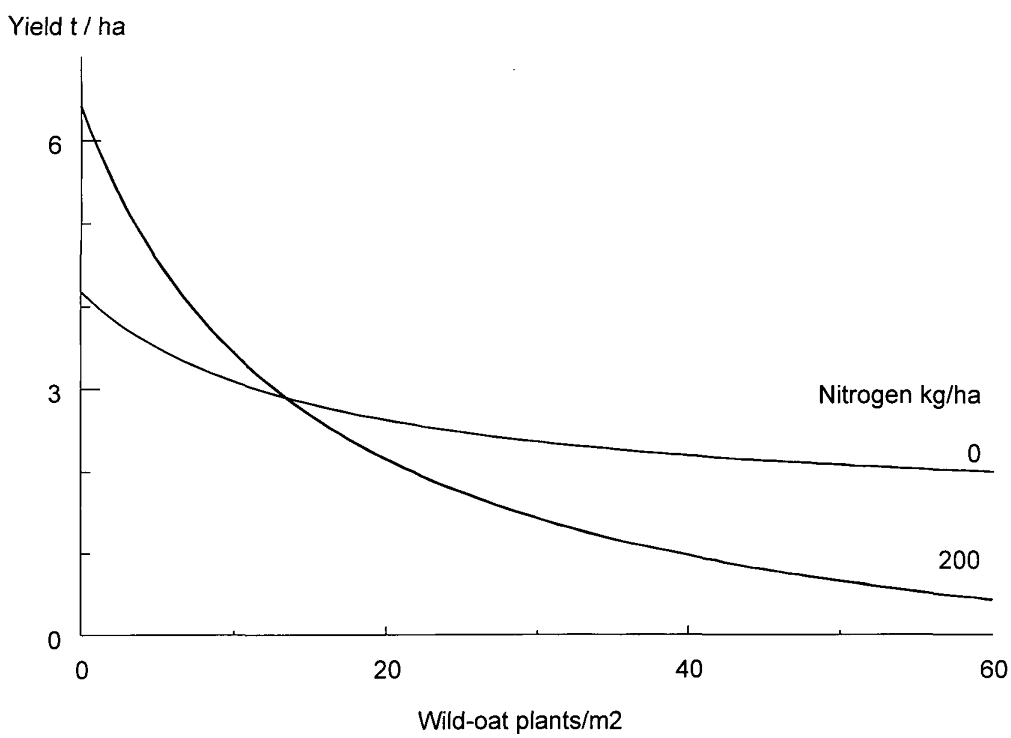
Figure 3.1.2 Effect of crop density on the competitiveness of poppy in terms of wheat yield losses and poppy seed production



3.1.1.3 Effect of N level on Weed Competition

The addition of nitrogen fertiliser is another competitive variable that has been studied. Cleavers and wild oat responded more to nitrogen than wheat. Uptake of nitrogen was greater by the weeds than the wheat crop, and yield losses from competition, and the production of weed seeds, were greater as the rate of nitrogen fertiliser increased. In the absence of weeds there was a yield response to 200 kg/ha of nitrogen of 2.3 t/ha. However, yield losses due to cleavers increased from 3.4 t/ha to 6.6 t/ha, and those due to wild oat from 2.2 t/ha to 6.0 t/ha as nitrogen fertiliser was increased from none to 200 kg/ha (Figure 3.1.3). This work suggests that, in competitive situations with these weed species, reductions in nitrogen fertiliser will benefit the crop relatively more than the weeds.

Figure 3.1.3 Effect of nitrogen fertiliser on wheat yield losses from wild-oats



3.1.2 COMPETITION IN SPRING BARLEY

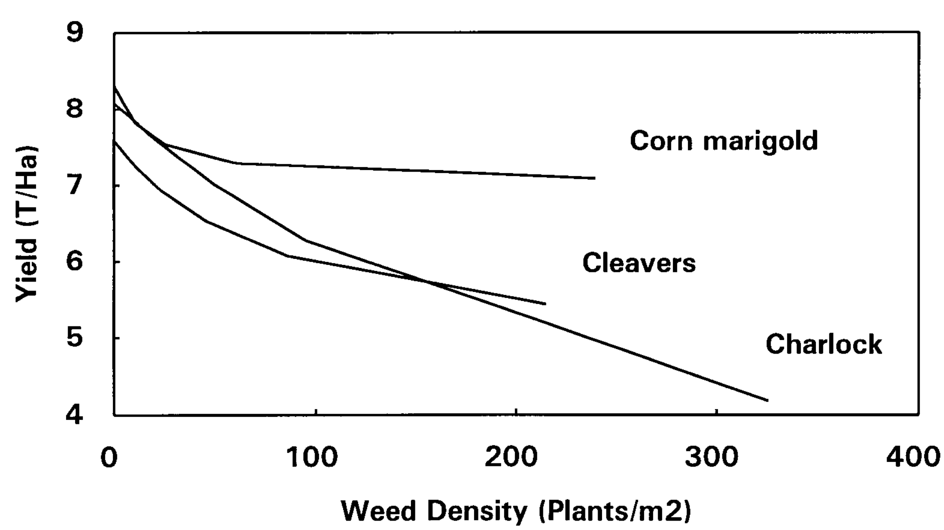
3.1.2.1 Species Comparison

The relative competitiveness of different weed species in spring barley was studied in two experiments. Charlock and wild oat were the only species to cause significant loss of yield. These species had mostly emerged before the three leaf stage of the crop; later emerging mayweed, fat-hen, fumitory, corn marigold, knotgrass and speedwell did not reduce yield. Late emergence relative to the crop, a high crop density (336 plants/m^2) in 1991, and drought in summer 1990, contributed to the lack of competitive effect from most of the sown species.

The 1991 experiment was repeated in Northern Ireland where competitive effects were recorded from a wider range of species. An initial experiment comparing 10 weed species at a range of densities in spring barley was conducted in 1988 which gave some initial information on pattern of weed development and C.E. values in spring barley This was followed in 1991 with a further experiment conducted in parallel with LARS.

In this experiment with a crop stand of about 200 plants per square metre it was possible to distinguish some degree of differential weed/crop competition.

Figure 3.1.4 Crop yield v weed density relationships for spring barley



Using the response relationships developed at LARS, Figure 3.1.4 shows that charlock and cleavers were the two most competitive species followed by corn marigold. Other weed species included (fat-hen, fumitory mayweed) failed to significantly depress crop yields. These data support the results from Long Ashton where charlock and wild oat were the only two species to cause significant yield loss. It is clear from the experiments at LARS and at QUB that spring barley at normal seeding rates and where summer drought occurs, as in 1990, strongly suppresses weed competition.

3.1.3 WEED POPULATION DYNAMICS

Work on population dynamics is prompted by the need to forecast changes in weed populations in response to reducing use of herbicides, in particular the potential build up of weeds from populations which are below a threshold level for spraying. Studies of the production of weed seeds, and the persistence of weed seeds in the soil were carried out at Long Ashton in conjunction with the Scottish Crop Research Institute.

3.1.3.1 Seed Production Studies

Seed production of five weed species was studied in relation to crop density and to nitrogen. The crop had a strong influence in limiting weed seed production (Table 3.1.4). In both years, seed production of red dead-nettle, pansy and poppy increased as crop density was lowered. Halving crop density approximately doubled the numbers of seeds produced. At the lowest crop density poppy was the most prolific species with over 40,000 seeds per plant in 1988. Seed production was lower in 1989, probably due to the summer drought.

Table 3.1.4 Effect of crop density on numbers of weed seeds/plant

	1988			**1989**		
No. wheat plants/m^2	207	114	40	189	115	45
Red dead-nettle	988	1989	4461	1394	1655	2359
Pansy	353	563	972	390	581	1576
Poppy	6029	12293	41213	2140	3441	8158

The effect of added nitrogen fertiliser on seed production of wild oat and cleavers is shown in Table 3.1.5. Seed production of both species was over three times greater at the highest nitrogen level compared with no nitrogen in 1990, and almost double in 1991. The greater seed production in 1991 was attributed to the wetter summer so that available moisture was less limiting.

Table 3.1.5 Effect of added nitrogen on numbers of weed seeds/plant

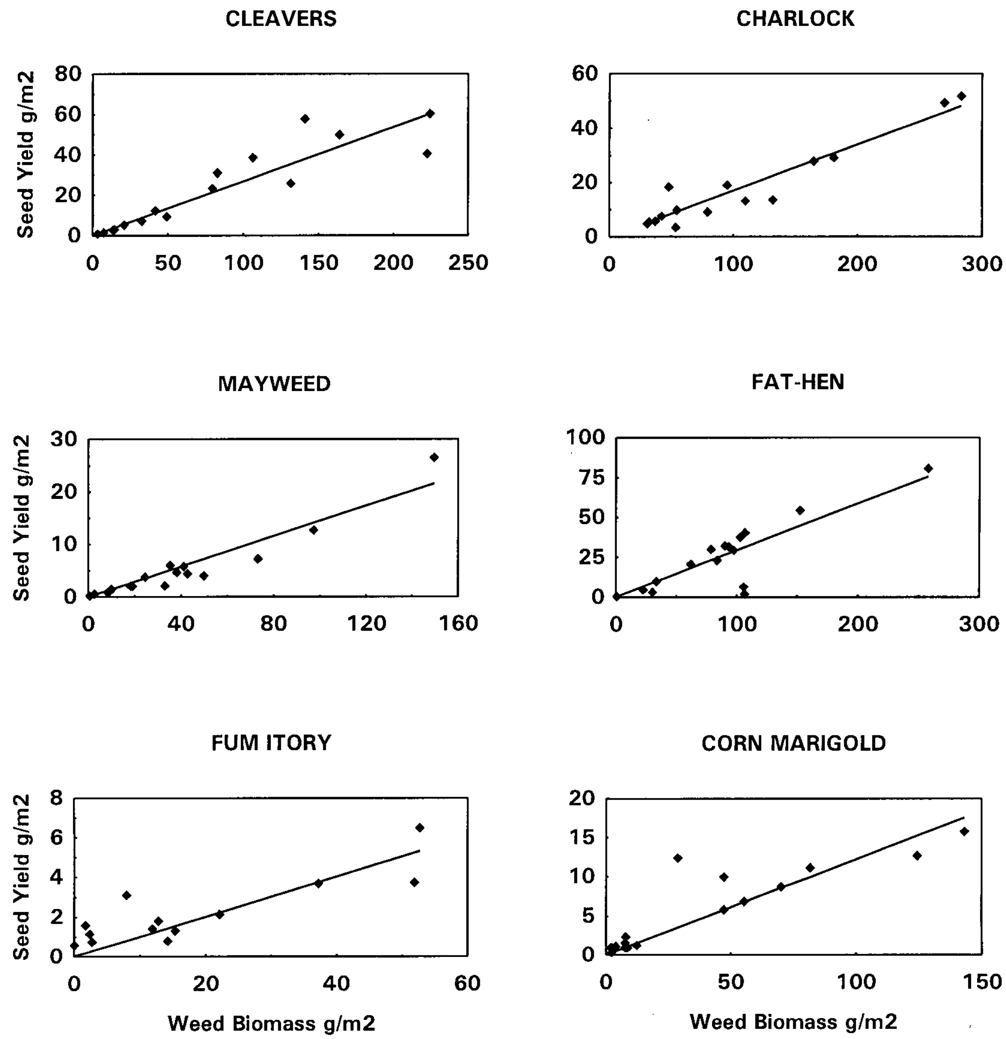
	Cleavers		**Wild Oat**	
N - kg/ha	**1990**	**1991**	**1990**	**1991**
0	65	273	416	530
50	95	329	692	869
100	149	359	808	1367
200	241	534	1469	1017
s.e.d. (9 df)	61.7	61.0	174.2	239.2

Studies of weed seed production are basic to further investigations of the losses of weed seeds, their persistence in the soil and the emergence of weed populations in subsequent crops.

3.1.3.2 Weed Seed Production Potential in Spring Barley

The weed density experiment in 1991 in N. Ireland provided additional information on relationships between weed biomass and seed production. These data (Figure 3.1.5) show that there were, in all the species compared, good relationships between weed biomass and seed output. This information will aid the prediction of weed population change in response to differing weed control strategies, particularly reduced herbicide rate regimes.

Figure 3.1.5 Weed biomass and seed production in spring barley



3.1.3.3 Seed Persistence Studies

Seedbanks and the emergence of weed seedlings, resulting from seeds shed in wheat crops and ploughed in, were monitored in two experiments between 1987 and 1990, in successive autumn sown crops. Herbicides were used to prevent re-seeding. Numbers of viable seeds, in the soil, of cleavers, poppy, red dead-nettle, forget-me-not, speedwell, pansy, ivy-leaved speedwell and chickweed decreased exponentially between years. Cleavers and ivy-leaved speedwell declined most, and poppy, pansy and chickweed least rapidly (Table 3.1.6).

Total weeds of all species which emerged over the 3-4 years represented only a very small proportion (between 3 and 4%) of the first year seedbank. Few seedlings emerged in the first year after seeding due to effective burial by the initial ploughing. The species showing the greatest emergence in the first year, relative to seedbank size, were cleavers and ivy-leaved speedwell (Table 3.1.7). Naturally occurring autumn germinating species showed similar patterns of seedbank persistence and emergence.

These results illustrate that the duration of the problem created by allowing weeds to return seeds to the soil can vary between 3 and 11 years, depending on species. Also, seedling emergence may not peak for several years thereafter. Both points need to be taken into consideration when weed control strategies are being designed.

Table 3.1.6 Exponential seedbank decline of individual species, based on fitted curves SE's based on more than 7 df)

	Annual decline %				Number of years to			
					50% decline		99% decline	
	Expt No		Weighted		Weighted		Weighted	
	1	2	Mean	SE	Mean	SE	Mean	SE
Cleavers	55.5	85.4	65.9	4.07	0.5	0.07	3.6	0.47
Poppy	24.9	43.9	34.7	6.53	1.3	0.32	8.7	2.13
Red dead-nettle	39.1	59.5	54.3	4.37	0.8	0.10	5.4	0.68
Forget-me-not	60.0	34.8	43.5	5.35	0.9	0.17	6.1	1.12
Field speedwell	58.3	36.0	45.8	6.92	0.9	0.21	6.1	1.37
Field pansy	36.4	36.4	36.4	3.74	1.5	0.20	10.2	1.32
Ivy-leaved speedwell	56.1	59.9	57.4	7.12	0.8	0.16	5.4	1.06
Chickweed	41.9	27.1	30.0	5.30	1.7	0.37	11.1	2.44

Table 3.1.7 Seedling emergence (numbers of seedlings/m^2) as a percentage of first year seedbank (numbers of seeds in soil/m^2 after initial seed shedding)

Species	Expt No	1987	1988	1989	1990
Cleavers	1	0.17	1.98	1.24	0.45
	2		1.92	0.84	1.34
Poppy	1	0.16	0.24	0.80	1.60
	2		0	1.43	1.46
Red dead-nettle	1	0	0.12	1.75	1.61
	2		0.05	3.25	2.73
Forget-me-not	1	0.10	0.14	0.36	0.22
	2		0.09	1.03	0.39
Field speedwell	1	0.05	0.13	1.96	1.34
	2		0.31	4.13	3.64
Field pansy	1	0.02	0.67	1.79	1.71
	2		0.03	1.71	2.49
Ivy-leaved	1	0.46	2.17	1.65	0.35
speedwell	2		1.98	0.71	2.02
Chickweed	1	0.07	0.04	0.59	0.36
	2		0.14	2.55	0.96

3.2 WEED COMPETITION STUDIES; SOURCES OF VARIATION IN C.E. VALUES AND WEED COMPETITION IN SPRING BARLEY

The order of variation in the growth and competitiveness of four weed species was studied in 14 crops of winter wheat, eight sites in 1987/1988 with cleavers, chickweed, and annual meadow-grass, six sites in 1988/89 with cleavers, chickweed, and poppy. Weed growth patterns were determined by harvesting samples on three dates. Site details are provided in Part 1 Appendix, Table 1 and have been more fully reported (Courtney *et al.*, 1990).

The experiments consisted of nine sites established in autumn 1987, and six sites in 1988. Subsequently two 1988 sites and two 1989 sites were excluded because take-all or invasive grass-weed infestation prohibited fair comparison between sites.

3.2.1 GLOBAL VARIATION IN C.E. VALUES

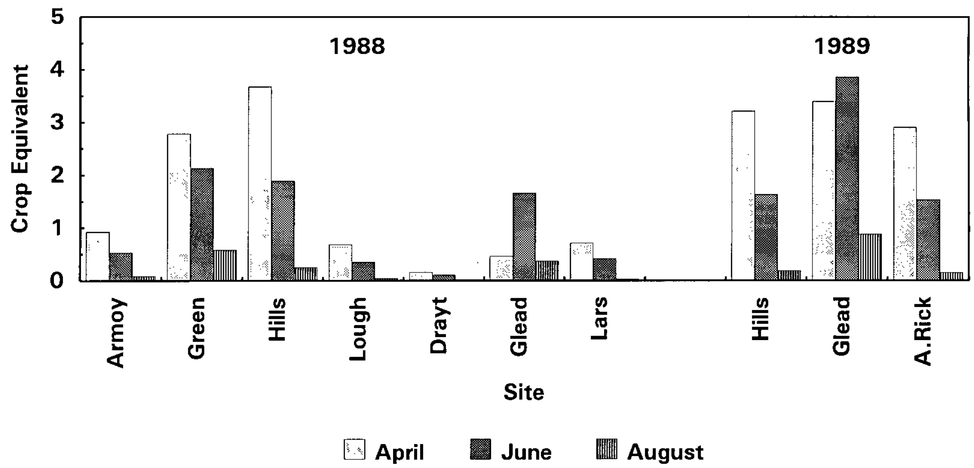
The series of experiments at sites throughout the UK provided an ideal opportunity to assess the order of variation in C.E. values between sites and years and the results for cleavers and chickweed allow this to be appreciated.

Table 3.2.1 Sites of C.E. trials and abbreviations in Figures 3.2.1.1 and 3.2.1.2

ENGLAND	**Abbreviation;**
Arthur Rickwood, ADAS Cambs.	A.Rick.
Gleadthorpe ADAS Notts.	Glead.
Long Ashton Research Station, Somerset	Lars.
Drayton ADAS Warwicks.	Drayt.
N. IRELAND	
Armoy, Antrim	Armoy.
Greenmount College, Antrim	Green.
Agricultural Research Institute Hillsborough, Antrim	Hills.
Plant Breeding Station Loughgall, Armagh	Lough.

3.2.1.1 Chickweed, C.E. values

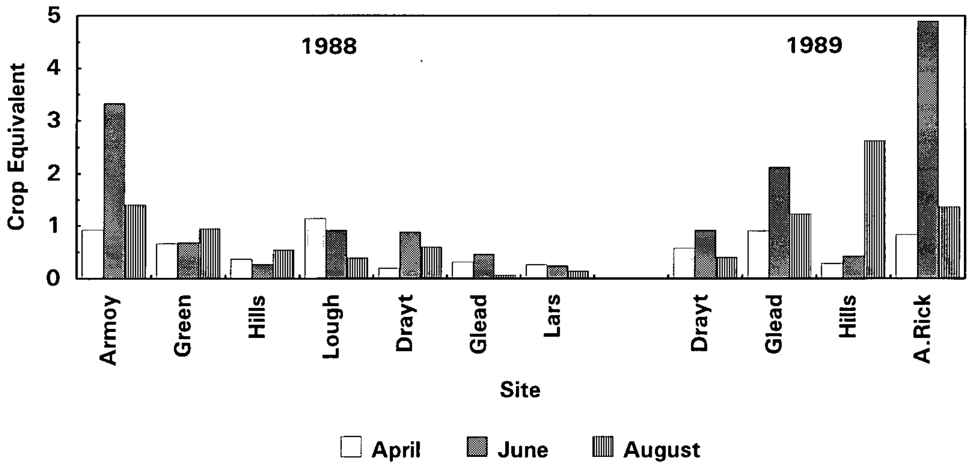
Figure 3.2.1 Chickweed; The effect of site and season on C.E. values



The development of chickweed followed the seasonal pattern of development described by Wilson & Wright (1990), in both years and at all sites, i.e. growth was early in the season and declined by the final harvest. Values for C.E. (Figure 3.2.1) followed this pattern. The peak value obtained in June, values ranged from 0.11-2.13 in 1988, and 1.65-3.60 in 1989. These are much higher than the value of 0.5 established by Wilson (1986), but higher values for C.E. of cleavers were also recorded in 1989. Whilst the differences between sites were significant at all harvests in 1988, they were only significant at the June harvest in 1989.

3.2.1.2 Cleavers, C.E. Values

Figure 3.2.2 Cleavers; Effect of site and season on C.E. values



There were definite site differences in the pattern of growth of cleavers. In the majority of sites (4 out of 7 in 1988, and 3 out of 4 in 1989) it followed the chickweed pattern of growth and had begun to decline by final harvest. This is in contrast to the four trials of Wilson & Wright (1987) conducted 1984-86, and two trials (1989) conducted 1986-87, where cleavers normally continued to grow until final harvest. C.E. values (Fig.3.2.2) ranged from 0.24-3.32 in 1988 and 0.42-4.90 in 1989 for the largest peak in June, and these are within the range observed by Wilson & Wright (1987).

These data indicate the range of weed development which has to be accommodated in predicting weed competition based on C.E. values. Of the individual site factors soil type and emergence date of the weeds relative to the crop were considered in more detail.

3.2.2 SOIL FACTORS

In the regional trials correlation coefficients for the C.E. of the 3 weed species at three harvests with % organic matter, sand, silt, and clay were calculated. No factors clearly accounted for the variation in C.E. of cleavers, but there are strong indications that the poppy C.E. is negatively related to organic matter content (r = 0.891, 0.557, 0.690, at 1st, 2nd, 3rd harvests). Initial growth was positively related to sand content (r = 0.789), and chickweed shows a similar non-significant tendency. All three weed species show a negative correlation to silt content early in their development (poppy r

= 0.943, cleavers r = 0.736) although this was not significant for chickweed. A further pot experiment in which cleavers were grown with winter wheat in a range of soil types at a site in N. Ireland failed however to demonstrate any good relationship between weed growth and soil type.

3.2.3 THE SIGNIFICANCE OF RELATIVE EMERGENCE OF CROP AND WEEDS ON C.E. VALUES

One of the potentially key factors which determines the competition between crop and weeds is the relative time of emergence of the crop and weeds (Håkansson 1986, 1991). The significance of this on the C.E. values of a range of weeds was compared in both winter wheat and spring barley.

In winter wheat this factor alone could account for a three fold difference in C.E. values in cleavers (Figure 3.2.3) and a very similar range of responses for pale persicaria, cleavers and poppy in spring barley (Figure 3.2.4). In spring barley earlier drilled crops were more competitive and reduced the developmental potential of the weeds (Figure 3.2.5).

Figure 3.2.3 Cleavers; The effect of weed establishment and sampling date on C.E. values in winter wheat

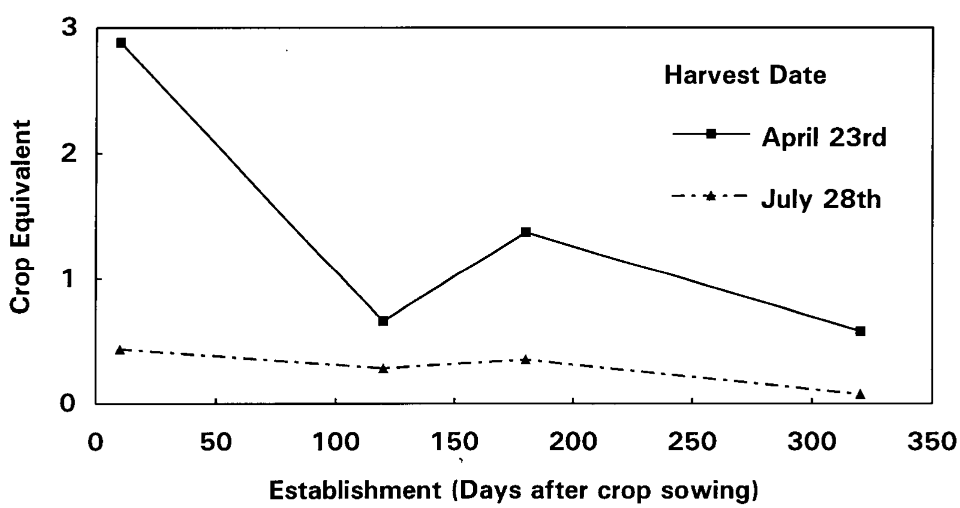


Figure 3.2.4 Effect of establishment date on C.E. values of weeds in spring barley

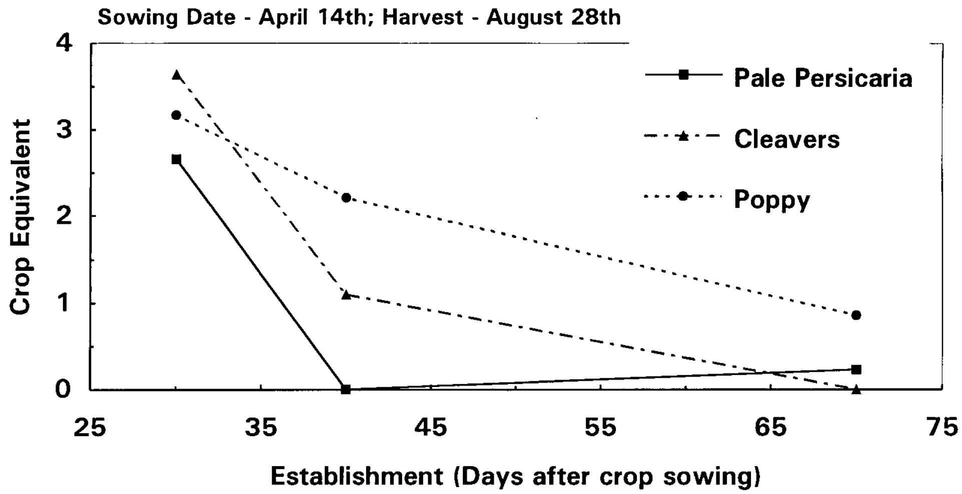
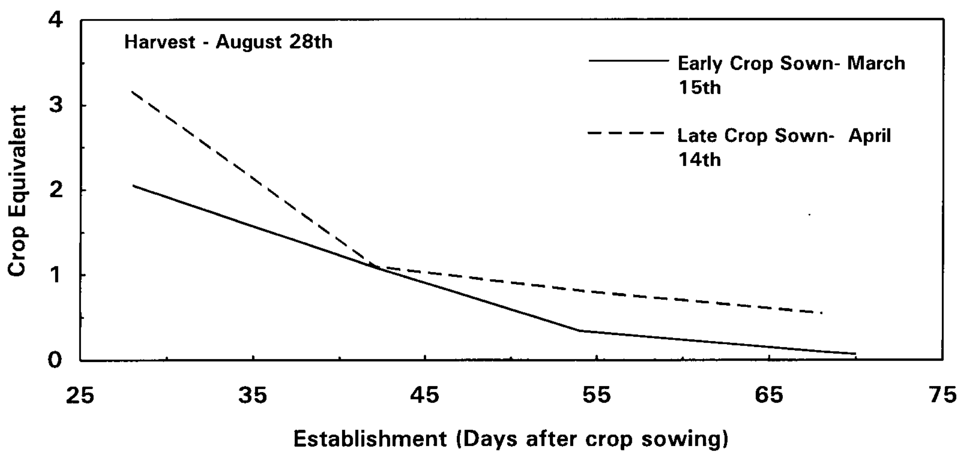


Figure 3.2.5 Effect of crop drilling date on C.E. values in spring barley



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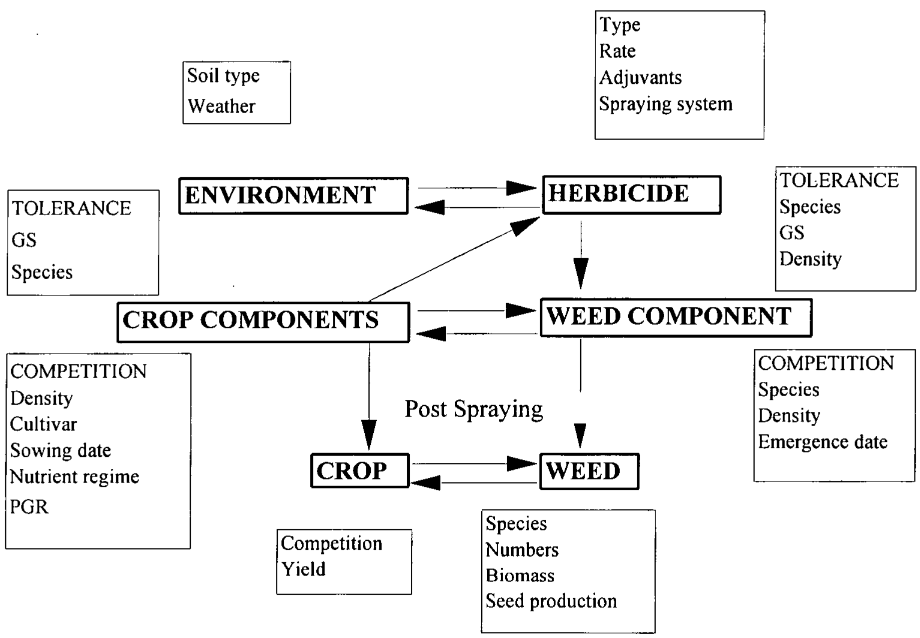
3.3 STUDIES TO INVESTIGATE THE BASIS OF HERBICIDE RESPONSE IN CEREALS

The potential for the adoption of a reduced rate herbicide strategy was evident at an early stage in the systems comparison in the current HGCA program and was supported also by associated trials results from SAC and DANI. As a consequence part of the cost-effective weed control program at QUB was directed at understanding some of the basic factors which might influence the rate response relationships of herbicides in cereals.

The components which influence herbicide efficacy are indicated in Figure 3.3.1.

Figure 3.3.1 Factors influencing herbicide performance



In conjunction with the field program comparing the adoption of weed threshold and half rate management decisions, the trials in N. Ireland sought to determine the potential significance of crop competition (density) on the performance of herbicides and the extent to which weed density influences herbicide performance and crop response.

The aim has been to understand the principles of crop and weed competition which govern the effective use of herbicides in cereals, rather than to evaluate the efficacy of individual chemicals.

Crop competition is undoubtedly the single most important factor influencing weed control and complementing herbicide efficacy (Salonen, 1990).

Although the basic relationships between weed density and crop yield have been amply demonstrated in recent years (Cousens 1985, Auld *et al.,* 1990), little attention has been given to the effect of weed density on herbicide efficacy or the interaction of weed removal and crop tolerance.

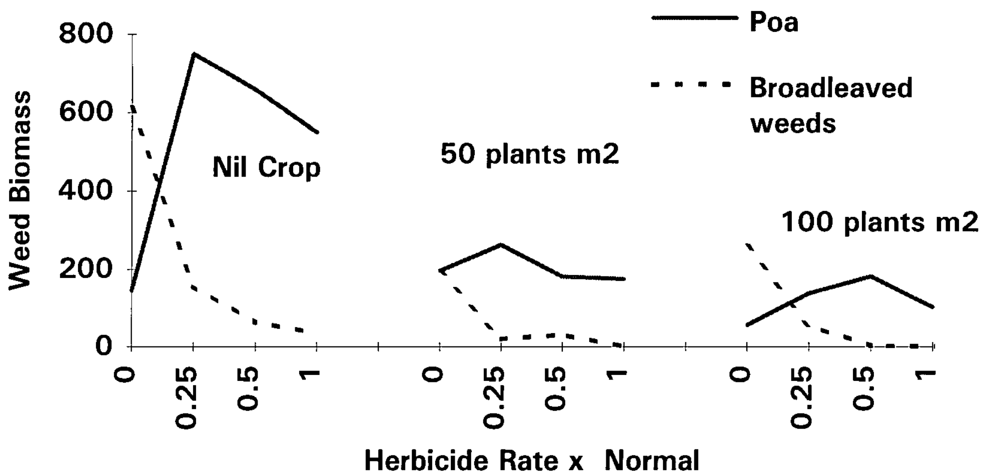
3.3.1 EFFECT OF CROP DENSITY ON HERBICIDE EFFICACY.

3.3.1.1 The Significance of Crop Density on Herbicide Efficacy in Spring Barley. Experiment 1 1990:

This experiment was carried out at the Agricultural Research Institute, N. Ireland and experimental details are given in the Part 1 Appendix. The data has been published in more detail (Courtney, 1991).

These data (Figure 3.3.2) suggest that, although the reduction of crop stand and competition reduces the herbicide efficacy of both broad-leaved and total weed biomass reduction, it was only in the absence of crop that the full rate of herbicide was necessary to maintain control of broad-leaved weeds. In spring barley, crop competition is sufficiently effective, even at crop levels of 50 m^2, to allow the use of reduced herbicide inputs. Competition from the crop complements the activity of the herbicide to maintain control of more tolerant species, which might otherwise increase if a reduced rate were used. An example in this experiment was the replacement of broad-leaved weeds by grasses. In the absence of the crop, grass weeds, mainly annual meadow-grass, quickly became dominant even with a full rate of herbicide. This replacement of broad-leaved species by annual meadow-grass is clearly illustrated at the 0.25 N (Normal) rate and the 0, 50 and 100 crop densities (Figure 3.3.2). The use of a higher rate and/or an increase in crop density tends to suppress this replacement process.

Figure 3.3.2 The influence of crop density on herbicide efficacy in spring barley



A similar although less dramatic change occurred between pale persicaria and the more tolerant knotgrass.

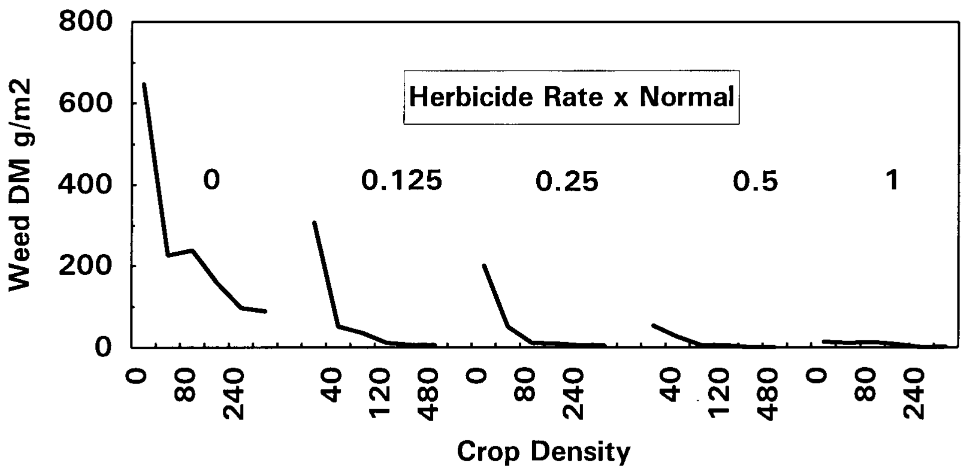
The crop yields reflect an increase with crop density and although not significant do tend to increase with rate of herbicide up to the recommended rate (Part 1 Appendix, Table 2).

These data show that although reduced rates down to 0.25 N rates gave total broad-leaved weed control over a wide range of crop densities, crop competition was important in preventing the replacement of susceptible by more tolerant species.

3.3.1.2 The Significance of Crop Density on Herbicide Efficacy in Winter Wheat. Experiment 2:

In this trial a range of rates of a herbicide program based on diflufenican/IPU in the autumn followed by metsulfuron-methyl in the spring were applied to winter wheat at a range of seed rates - nil, 40, 80, 120, 240, 480 seeds/m^2. For details see Part 1 Appendix, Table 3. Weed numbers in February showed a significant effect between untreated and herbicide - treated plots, but no difference between any of the rates. In April, before the spring application, crop competition was clearly aiding weed control as assessed by weed biomass; this interaction was maintained through to a biomass sampling in June (Figure 3.3.3). This illustrated the significance of crop density in the absence of herbicide and the way in which herbicide rate progressively diminishes this dependence on crop competition to maintain weed control. At this site, however, even the $^1/_8$ rate herbicide program gave excellent weed control (Figure 3.3.3) and produced a significant yield response which was not increased by higher rates of herbicide (Part 1 Appendix, Table 3).

Figure 3.3.3 The influence of crop density on herbicide efficacy in winter wheat



3.3.2 EFFECT OF WEED DENSITY ON HERBICIDE EFFICACY

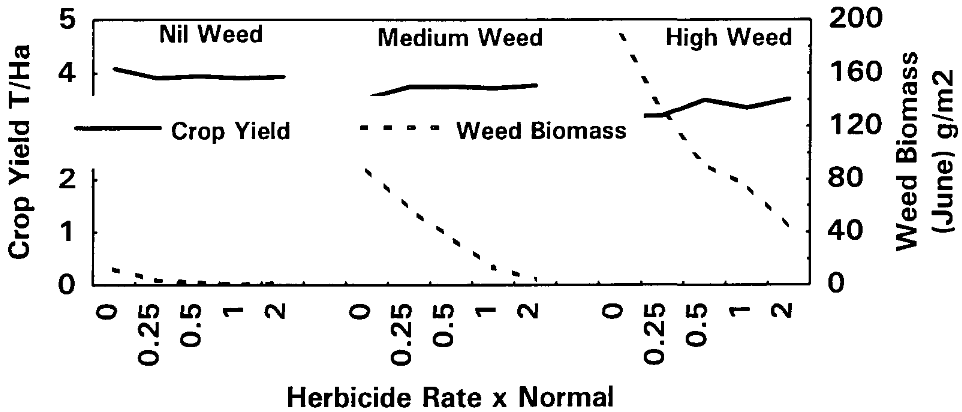
3.3.2.1 A Simulation Study with Oilseed Rape to Define Weed Density. Effects on Herbicide Efficacy and Yield Response in Spring Barley.

Commencing in 1989 a series of trials were conducted with oilseed rape in spring barley to simulate a range of weed infestation levels.

Experiment 1.

In 1989 at a farm site in Co. Down oilseed rape was broadcast into a spring barley crop at three rates - zero, medium and high giving 0, 97 and 351 plants m^2. Three herbicides, metsulfuron-methyl (Ally, Dupont U.K. Ltd.), MCPA/dichloroprop (Hemoxone, Plant Protection Ltd.) and Fluroxypyr/HBN (Advance, Plant Protection Ltd.) were applied on 7th June at 0.25, 0.5, 1.0 and 2.0 the normal recommended rates. Biomass samples, $0.5m^2$ per plot were taken on 24 June 1991 and combine yields were recorded at harvest.

Figure 3.3.4 The effect of simulated weed density on control and yield response in spring barley



The weed biomass of the oilseed rape in July, some four weeks after spraying, and the grain yield data are shown in Figure 3.3.4.

These are the mean data for the three herbicides. In the absence of significant weed competition (Nil Weed), there is an indication of a reduction in yield from all the herbicide rates. As competition was increased, at the medium weed level, weed control increased progressively through to the highest rate of herbicide. Yield, however, although it was increased by $^1/_4$ N rate of herbicide, showed little further response to the herbicide. The yields failed to recover to the levels in the weed free treatment. With the highest simulated weed density the residual weed biomass was higher than in the medium and nil weed situations. In this instance the yield increased up to the $^1/_2$ N rate and little above that. The residual effects of the competition, which, even at the time of spraying, had severely reduced tiller and leaf numbers, limited the crop response to weed control.

Experiment 2

This experiment was repeated at Greenmount Agricultural College, Co. Antrim during 1991 with a larger range of simulated weed densities. (For details see Part 1 Appendix, Experiment 2).

The 1991 data, for weed and crop biomass in July and grain yield at harvest, confirmed the main effects observed in the first experiment (Figure 3.3.5).

Figure 3.3.5 The effect of weed density on the mean response to herbicide for weed control and crop biomass response

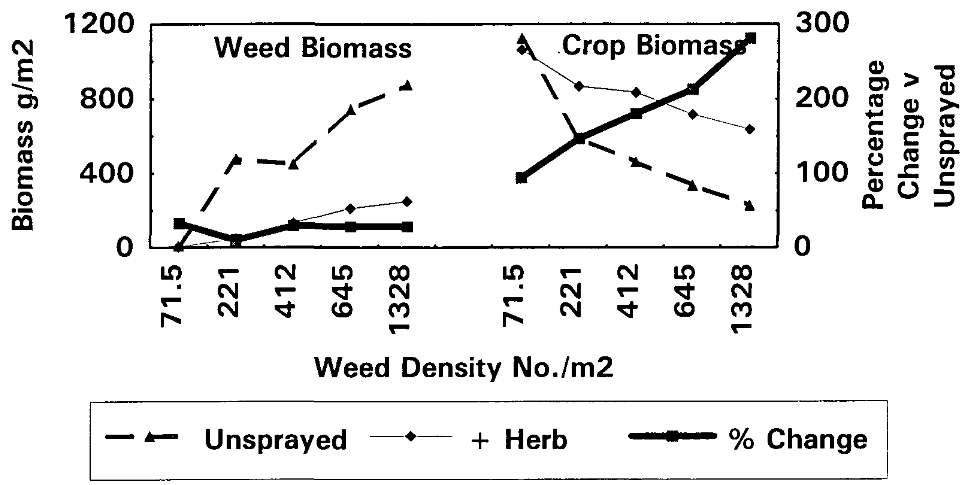


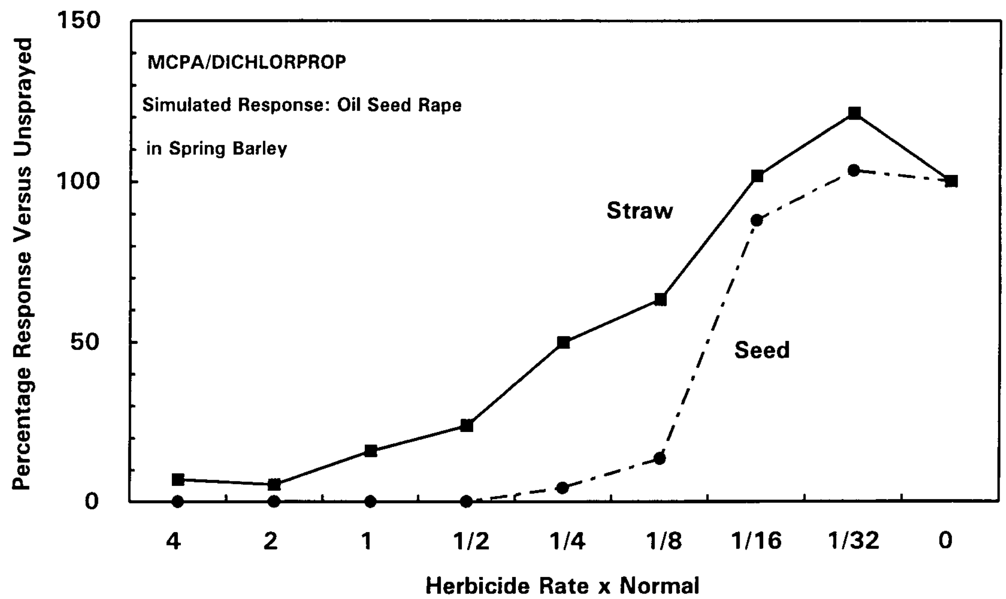
Figure. 3.3.5 shows the basic response to herbicide meaned over herbicides and rates. Herbicide efficacy (percentage weed control), remained constant at all weed densities. This is confirmed by some preliminary modelling of the data at Long Ashton Research Station which failed to show any interaction between weed density and herbicide efficacy at any of the rates and herbicides tested (Brain, pers. comm.).

The yield response in absolute terms, biomass increase and percentage change relative to the control, increased with increasing weed density. At the higher weed densities the crop failed to compensate fully for the removal of the weed and both biomass and yield (not presented) decline as weed density increases. This may be attributed to the higher residual weed biomass at the higher oilseed rape densities.

3.3.3 THE EFFECT OF HERBICIDE ON WEED SEED PRODUCTION

In 1991 an experiment in spring barley using oilseed rape as a simulated weed, investigated the effect of herbicide rate on biomass and subsequent seed production. The data from this experiment for MCPA/dichloroprop indicated that in oilseed rape, seed production was about 4 times as sensitive to herbicide as was biomass in the form of stem/straw production (Figure 3.3.6). If this applies in a similar way to weed species then it is probable, except where very tolerant weeds occur, that a reduced rate herbicide regime should not encourage a longer term increase in the seed bank.

Figure 3.3.6 The relative effect of herbicide rate on biomass and seed production



3.3.4 CONCLUSIONS

The prime importance of crop competition in complementing herbicide activity in cereals has long been recognised (Pfieffer and Holmes, 1961) from the work on control of wild oat with barban and more recently the studies by Ervio (1983) and Salonen (1990). The experiments on both winter wheat and spring barley, although they require further confirmation, indicate that effective broad-leaved weed control could be maintained even at low crop densities. They also demonstrate that crop competition interacts with herbicide efficacy and is likely to become of crucial importance, for the control of more tolerant weeds, as herbicide rates are reduced.

The simulation studies with oilseed rape are important in exploring the basic competition and herbicide response relationships. They indicate that weed density does influence the amount of residual weed after spraying and the recovery potential of the crop. Although the simulated OSR densities were designed to cover the extreme situations they suggest that weed density may very well combine with environmental constraints on herbicide activity to diminish weed control and crop yield.

In a number of instances the fact that optimum yield response occurs in advance of total weed control raises the issue of how much weed control is required, to achieve the benefits of weed removal, without the expression of crop phytotoxicity.

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PART 2

FIELD TRIALS AND SEEDBANK STUDIES

4.1 COST-EFFECTIVE WEED CONTROL IN CEREALS: FARM TRIALS

4.1.1 INTRODUCTION

A series of trials on farm cereal-based rotations throughout the United Kingdom was established in season 1987/88, designed to test in practice the short- and long-term effects of weed management systems based on weed threshold models developed at Long Ashton Research Station (IACR). The trials evaluated the potential savings in herbicide usage, the short- and long-term costs of changes in weed control practice and the practical problems of weed threshold assessment. The series was funded by the HGCA with underpinning by MAFF, DANI and SOAFD (ex-DAFS).

The sites were managed for four seasons using the weed control regimes described in Section 4.1.2 below, with HGCA and Government funding. A few sites are still being managed under Government funding to look at longer-term aspects of leaving low levels of weeds in rotations. This report summarizes the results from the first four years of the rotations.

4.1.2 EXPERIMENTAL DESIGN AND SITES

The trial sites are established on commercial farms or commercial fields on experimental farms. Full details of sites are given in Part 2 Appendix, Table 1.

ADAS

ADAS Bridgets, Winchester, Hampshire
ADAS Drayton, Stratford-on-Avon, Warwickshire
ADAS Gleadthorpe, Mansfield, Nottinghamshire
ADAS Rosemaund, Herefordshire
ADAS Cambridge site - stopped in 1989 because of grass weeds
ADAS Star Cross, Exeter, Cornwall

SAC

Smith's Holding, Bush Estate, Edinburgh
J Crichton, Niddrie Mains, West Lothian
N Paton, Gleghornie, East Lothian
J Stewart, Remote, Midlothian

The Queen's University of Belfast, (QUB)

J Orr, Strangford, Co. Down

The sites were not all in continuous cereals. Where other crops appeared in the rotation, attempts were made to maximise weed control in those crops so as not to interfere with the development of the weed flora in the cereal part of the rotation.

The treatments in the cereal crops were as follows:

1.* Full insurance herbicide treatments
2. Autumn insurance (broad-leaved weed (blw) and grass weed control in autumn; blw control if threshold triggered in spring)
3. Autumn grass insurance (grass controlled in autumn, no specific blw control; blw control if threshold triggered in spring)
4.* Threshold management; triggered by threshold level
5.* Half-rate full insurance treatment
6. Half-rate autumn insurance treatment
7. Half-rate autumn grass insurance treatment
8* Half-rate threshold management herbicides
9. UNTREATED with herbicides (SAC and QUB sites)
10. Treatments replicated +/- pre-harvest glyphosate (SAC sites)

* Core treatments, applied at all sites. 2,3,6,7 at ADAS and QUB.

There were three replicates per treatment. All treatments were applied in a medium spray (BCPC) in 200 l/ha volume. Plot size allowed harvesting by combine.

4.1.3 THRESHOLD ASSESSMENT

Threshold assessment was undertaken by weed plant counts with quadrats to assess levels per square metre. Using the formula developed at Long Ashton Research Station, a total C.E. (C.E.) of weeds was calculated for each spray occasion. The spray threshold was triggered at 5.0 C.E./m^2, except where black-grass or cleavers were present, when a threshold of 0.5 C.E./m^2 was used.

Spray thresholds were exceeded by weed populations on most spray occasions at most sites (Table 4.1.1). For detailed records see, Part 2 Appendix, Table 2. The sites were initially chosen as not being particularly weedy, and some were considered as having low populations; so it is assumed that, in practice, spray thresholds would generally be triggered if used in conventional farming. At the Cambridge site, grass weed populations increased very quickly to levels which were not controlled even by the full-rate insurance treatments. The site was abandoned after two seasons.

Table 4.1.1 Percentage of occasions that spray thresholds were triggered in each season of the trial series (All sites)

	% of all spray occasions
1987/88	80
1988/89	56
1989/90	79
1990/91	84

Weed populations were generally lower in 1988/89, probably because of dry soil conditions at critical emergence periods.

4.1.4 HERBICIDES USED

Herbicide use varied between sites, but where possible remained within a restricted range of products. Early autumn insurance treatments were generally based on diflufenican + isoproturon (DFF+IPU) at all sites. Later autumn treatments were based on combinations of IPU, ioxynil, bromoxynil and mecoprop, although diclofop and bifenox + IPU were also used. In the spring, combinations of metsulfuron methyl +/- thifensulfuron methyl, with or without mecoprop, tended to be used. There was some use of IPU for grass weed control, and fenoxaprop-ethyl was used in 1990/91 at ADAS Bridgets.

Overall, there was surprisingly little difference in the levels of weed control achieved over the seasons between full and half-rates of herbicides at all sites. An exception was late autumn treatments in dry conditions in season 1989/90.

4.1.5 CROP YIELD

The overall lack of difference in levels of weed control achieved between half and full-rates of routine insurance herbicide treatment is reflected in lack of yield difference (Table 4.1.2). There was, however, a tendency for half-rate treatment not to be as effective in yield terms as the full-rate when plots were not treated until threshold levels were exceeded. In general, differences in yield responses were small, and this was also true between treated and untreated plots at the Scottish and Northern

Irish wheat sites. In contrast, at the site in continuous winter barley for three seasons (Smith's Holding, Bush), there was evidence of a major weed build-up and reduced yield in the threshold-triggered treatments. Even half-rate insurance treatment gave insufficient control at this site.

Table 4.1.2 Average yield (t/ha) from winter wheat, spring barley and winter barley crops at all sites, 1987-91 (excludes Cambridge and late added S W Region sites)

3a) WINTER WHEAT

Treatment	ADAS(*17*)		SAC(*7*)		QUB(*2*)		ALL(+)	
Rate:	N	1/2N	N	1/2N	N	1.2N	N	1/2N
Full insurance	6.88	6.84	8.99	9.01	8.85	8.94	7.60	7.69
Autumn insur.	6.82	6.68	-	-	8.39	8.92	-	-
Grass insur.	6.80	6.50	-	-	8.53	8.41	-	-
Threshold	6.85	6.54	9.03	9.08	8.41	8.77	7.56	7.39
Untreated	-		8.83		8.40		-	

3b) SPRING BARLEY **3c) WINTER BARLEY**

Treatment	SAC(*5*)		SAC(*3*)	
Rate:	N	1/2N	N	1/2N
Full insurance	7.90	7.90	7.92	7.52
Threshold	7.97	7.73	7.76	7.12
Untreated	7.69		6.46	

(*n*) No. crops; N = full recommended herbicide rate; 1/2N = half recommended herbicide rate; (+) where comparison can be made.

4.1.6 HARVESTING (SAC SITES)

A pre-harvest glyphosate (1.5 l/ha Roundup; Monsanto plc) treatment was applied to replicates of all treatments at the Scottish sites, to evaluate the possibility of using the treatment as an emergency follow-up where early weed control from reduced herbicide use was inadequate to prevent harvesting problems. The treatment was included to evaluate the impact of leaving weeds below threshold levels on grain harvest and quality. The impact of the treatment was measured at all sites in 1988 and 1991, otherwise only where such a treatment was most likely to have had an impact.

4.1.6.1 Straw Dry Matter

The use of pre-harvest glyphosate reduced straw dry matter significantly on five out of nine occasions where tested (Part 2 Appendix, Table 4).

4.1.6.2 Moisture Content of Grain

Use of pre-harvest glyphosate improved grain moisture content by 0.5% or more in three out of nine harvests tested (Table 4.1.3). However, the difference is unlikely to recompense for the cost of treatment.

Table 4.1.3 Effect of pre-harvest glyphosate on % moisture content of grain

	Glyphosate							
	+				-			
Site:	Niddrie Mains	Gleg-hornie	Remote	Bush	Niddrie Mains	Gleg-hornie	Remote	Bush
1991	20.0	17.5	15.9	-	19.4	17.5	15.6	-
1990	16.6	-	18.3	-	17.7	-	19.3	-
1989	-	-	-	13.6	-	-	-	13.7
1988	16.2	21.7	16.9	20.7	16.1	22.1	17.0	20.6

4.1.6.3 Thousand Grain Weight and Grain Specific Weight.

There was no clear pattern of response in 1000 grain weight or grain specific weight to the use of glyphosate preharvest, where evaluated. However, 1000 grain weight was significantly lower in untreated plots at two out of five sites evaluated, and specific weight at two out of three sites (Part 2 Appendix, Table 5). These were the weedier sites.

Matter other than grain (MOG) throughput reduced, due to improved combine speed, at five out of seven sites recorded, where glyphosate had been used pre-harvest (Table 4.1.4). This was due to reduced straw weight (moisture) and reduced weed matter (and moisture). The improvement in combine efficiency has been noted from earlier studies (Sheppard *et al.,* 1989). There was a significant increase in MOG throughput from untreated plots at most weedier sites.

The greater the MOG throughput the higher the yield loss through the combine unless the forward speed is reduced. This is illustrated in Part 2, Appendix, Figure 6c. Very high levels of weeds at harvest, as illustrated by the Bush site in 1990 can lead to very high losses. The high levels of chickweed at Bush in 1990 led to a loss of 3t/ha grain in untreated plots (Part 2 Appendix, Table 6B).

Table 4.1.4 Effect of pre-harvest glyphosate on MOG throughput (t/ha)

		Glyphosate	
		+	-
Year	Site		
1991	Gleghornie	4.13	3.81
	N Mains	4.25	4.36 S
	Remote	2.83	3.01 S
1990	Bush	3.37	3.38
1988	Gleghornie	3.59	3.87 S
	N Mains	4.90	5.02 S
	Remote	5.96	6.06

4.1.7 ECONOMIC ANALYSIS

4.1.7.1 Winter Wheat

Table 4.1.5 gives the average improvement over 1988-91 harvests in margin over herbicide costs relative to those of full-rate insurance herbicide treatments, in the wheat crops tested. Application costs are not included, nor are the future costs of poor weed control; i.e. harvest and seed quality factors and weed seedbank changes. All treatments improved margins over full-rate insurance, herbicide costs, whilst half-rates are clearly preferable to full-rates of any treatment. The half-rate threshold treatment generally gave the best economic response despite slightly lower overall yield response (Table 4.1.5). This is, of course, strongly affected by the times when the threshold is not exceeded, so no herbicide is applied. This was particularly the case at the less weedy Scottish sites. However, if the time taken to assess the weed populations is taken into full account, then half-rate, full insurance treatments would have proved the most economic approach in these situations. The high margins over full-rate, full insurance spraying reflects lack of yield response to higher rates.

Table 4.1.5 Average margin (£/ha) over herbicide costs (MOHC) per site relative to MOHC for full-rate full insurance treatment; winter wheat (17 sites)

	Full-rate	Half-rate
Insurance treatment	0	+67 (268)
Threshold treatment	+24 (96)	+92 (368)

( ) cumulative average/site/over 4 seasons/ha
Assumes winter wheat @ £100/t

4.1.7.2 Spring Barley

The spring barley sites were not very weedy, and yield responses were very variable, with little or no response to herbicide use. This is reflected in the variable margins, with untreated plots giving a similar margin to the threshold full-rate plots, which were seldom treated (Part 2, Appendix, Table 8).

4.1.7.3 Winter Barley

The large response to weed control at the one winter barley site, over three seasons, is reflected in the large yield reductions, and consequent margin reductions, whenever less than the full-rate, full insurance treatment was used. Such a strong response to weeds is common in winter barley compared with other cereals (Davies, 1987).

4.1.7.4 Costs of threshold assessment

It is estimated that using the intensity of measurement employed on the English test sites, where 48 x 0.1 square metre quadrats were taken at 2-3 minutes/sample, it would take up to 40 hours to complete the full assessment of a hectare. Using an error acceptance of 20%, ADAS Drayton have calculated that 8 - 30 samples/ha would, in practice, give adequate precision, at an estimated cost of up to £52/ha/potential spray occasion. In comparison, the insurance treatments would have had, a much less costly yes/no or full/half-rate/no herbicide decision made based on overall assessment and experience. We have calculated a mean benefit over all sites and rotations for the half-rate insurance and full threshold treatments over the full insurance full-rate treatment program (Table 4.1.6) including assessment and spray costs.

It is clear from Table 4.1.6 that the cost of the threshold approach used is considerable, and that, at these sites, the routine use of half-rate insurance treatment is more likely to prove profitable. However, this is a generalisation and weed populations at some sites (e.g. Smith's at Bush) are not being controlled by half-rate insurance treatments. The fact that the untreated plots at the Scottish and Northern Irish sites are apparently the best option is due to the lack of yield response to treatment on many occasions. However, weed populations quickly built up on those plots in years three and four.

Table 4.1.6 Mean margin of improvement (£/ha)* over treatment and assessment costs in rotations over 9 sites, 1988-1991, over full-rate full insurance treatment

	Full-rate		Half-rate
Insurance treatment	0		+ 42.4
Threshold treatment	- 253.7		- 233.8
Untreated (5 sites only)		+ 70.4	

*Based on: net yield benefit based on all cereals at £100/tonne @ 85% dry matter; herbicide costs based on £25/ha per timing (two timings in winter crops and one in spring barley); spraying costs based on contractor costs of £8/ha; assessment costs based on 20% of adviser or consultant time at £5/ha/annum for routine weed assessments and £52/ha/timing for threshold evaluation.

4.1.8 WEED POPULATION CHANGES

Seasonal ploughing affects the pattern of weed seed distribution, so that there is not a straightforward annual increase in weeds. Seasonal weather patterns and time of sowing will also have an effect. Nevertheless, there was a clear increase in the major weed species at the Scottish sites, and the Northern Irish site (Part 2, Appendix, Table 9). There was a similar, although less clear, trend at the English sites in continuous winter wheat. Part 2 Appendix, Table 10 gives the C.E. values of weeds remaining after treatments at the English sites. Data from Bridgets show that in 1991 even very high levels of insurance treatment did not fully control weeds. Also, the results from Bridget's and Drayton show that, unlike in earlier years, there were more weeds left over after half-rate than full-rate treatments.

The largest change in weed population seen during this series was that of the Bush site, following three seasons of winter barley, 1988/90. The 1991 season was a break-crop. Chickweed populations increased twenty-fold in untreated and threshold (not treated in first season) plots. Even full insurance plots showed a significant increase in this weed.

In general, weeds increased less in insurance treated plots than threshold treated plots. Data from the English sites show more weeds left in half than full insurance plots after four seasons. Weed seedbank changes at these sites are described in Section 4.2.

4.1.9 GENERAL CONCLUSIONS

The Long Ashton threshold evaluation model proved to be a successful method in wheat and possibly, spring barley, of managing a crop from the point of view of margin over costs of herbicide. These sites were not selected as being particularly weedy, and yet the threshold weed levels were generally exceeded on over 70% of spray occasions. The costs of assessment proved high, and greatly exceeded any benefit over routine use of half-dose insurance spraying. On occasion, leaving threshold levels of weeds caused a problem at harvest, mainly through higher MOG levels. Glyphosate used pre-harvest reduced straw weight and MOG due to desiccation, and this would probably allow an increase in combine efficiency, but there was little or no benefit in grain moisture content. The treatment is available as a back-up to use when threshold evaluation fails, and its main benefit would be to increase harvesting efficiency, but it would probably be cheaper to use reduced herbicide insurance treatments than rely on the back-up pre-harvest treatment.

There is some evidence that weed and weed seed levels are beginning to increase in threshold managed plots. This may be a particular problem where winter barley is in the rotation; potentially a particularly 'weedy' crop. Such changes in weed populations will increase still further the proportion of occasions when spray thresholds are exceeded in future seasons. There is some evidence from the assessments in 1991 of a move in this direction, but several more seasons must elapse before the trend can be confirmed. The build-up of weed populations with time suggests that the thresholds used in this study, although already risk aversive, were too high for long-term use in some situations. Furthermore, the sites selected in this experiment had been well managed and were chosen for their modest weed populations. This compounds the expectation that in many weedier, commercial crops the thresholds would be exceeded even more frequently and their usefulness further diminished.

However, these studies were the first large-scale trialling of an experimental threshold approach. For some weed species/crop combinations the thresholds were based on informed opinion. There is evidence of some merit in the threshold principle, perhaps modified to overcome some of the practical limitations. The current technique requires a high degree of assessment to ensure only a 20% error factor, whereas in practice the need is for a method that allows much more rapid, yet accurate, evaluation. Any novel approach could perhaps also help to judge herbicide dose in a more flexible manner than the 'spray/no spray' approach compared here. A lower 'no spray' threshold might then be used, reducing the potential for continued weed growth to cause problems at harvest or allow the build-up of weed seedbanks.

It is also clear that if cereal prices drop, the costs of assessment must, as must the cost of treatment, be reduced. It is the point at which increased assessment profitably benefits reduced herbicide cost that must be determined.

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4.2 LONG-TERM EFFECTS OF REDUCED HERBICIDE INPUTS IN CEREALS ON WEED SEEDBANKS IN THE SOIL.

4.2.1 ABSTRACT

Soil samples were collected and analysed for weed seed content four years after the start of a series of long-term experiments on methods of reducing herbicide inputs in cereal rotations. Seedbank records indicated that the most sustainable herbicide reduction strategy evaluated involved the application of broad-spectrum herbicides prophylactically every year, but at half the normal dose. Overall this treatment kept weed seed populations slightly lower than those on plots where weed control applications had been based wholly or in part on threshold spray/no spray decisions. This conclusion was confirmed by counts of unsprayed weed seedlings in the third or fourth crops at each site. At several sites where crops remained totally untreated with herbicides for four years weed seedbanks in the soil increased considerably. To some extent this was reduced by pre-harvest desiccation with glyphosate.

4.2.2 OBJECTIVES

To extract and analyse the seed content of soil samples from long-term trials on the effects of reducing herbicide inputs in cereal rotations and to contribute to the assessment of the sustainability of the different weed control strategies used.

4.2.3 INTRODUCTION

Economic and environmental pressures are forcing farmers to look for ways of reducing herbicide inputs into cereal crops. If this can be done without lowering the standards of weed control achieved, then weed management strategies may not need to change. However, if it involves accepting higher levels of weediness in individual crops and the survival of weeds to seed, then the situation must be considered from the rotational viewpoint as well as that of potential problems for the individual crop. Might savings in the shorter term lead to crop losses or greater expenditure on weed control in the longer term? It was to seek answers to this amongst other questions that a series of long-term experiments was established in 1987 in a collaborative program initially funded by HGCA and managed jointly by scientists from the Agricultural Development and Advisory Service, the Institute of Agricultural Crops Research, the Scottish Agricultural College, the Scottish Crop Research Institute and Queen's University, Belfast. Funding of the main program by HGCA ceased in 1991, but an additional one-year contract was awarded to SCRI to allow assessment of the impact of four years of the various experimental treatments on the soil seedbank. This report deals with that assessment and the implications for rotational weed control strategies.

4.2.4 BACKGROUND INFORMATION

4.2.4.1 Experimental Details

Nine long-term field trials were established in 1987, four on ADAS experimental farms in England, four on commercial farms in Scotland and one in Northern Ireland. The English sites were cropped mainly with continuous winter wheat, whereas winter barley, spring barley and spring wheat also featured in the rotations at the other sites. The experiments were designed primarily to examine ways of reducing inputs for broad-leaved weed control, using two contrasting approaches, i.e. reduced rates and thresholds. Regimes common to all sites were as follows:

Full insurance - Grasses and broad-leaved weeds were controlled prophylactically in autumn and/or spring every year.

Threshold - Herbicides were either applied or not applied in autumn and/or spring, on the basis of arbitrary fixed thresholds.

In both cases spray applications were made using either the normal commercially recommended rate or one-half of that rate of application of the herbicides chosen. The ADAS and QUB sites also had two intermediate regimes involving insurance treatment of grass weeds only or of grass and broad-leaved weeds in autumn, with thresholds used to determine weed control needs in spring. The SAC sites included the presence or absence of routine pre-harvest desiccation with glyphosate to reduce potential problems resulting from uncontrolled weeds. In addition, the SAC and QUB sites included untreated plots against which the various herbicide strategies could be assessed. Plot size was 12 m by 50 m (ADAS and QUB sites) or 4 m by 27 m (SAC sites) and there were three replicates of each treatment arranged in a randomised block layout.

Threshold spray decisions were based on the Crop Equivalent (C.E.) system developed at IACR Long Ashton (Cousens, Wilson and Cussans, 1985), in which each weed species is assigned a C.E. value according to its competitiveness. The higher the C.E. value, the more aggressive the weed. Emerged weeds are counted and identified, the total C.E. per square metre is calculated and a spray treatment is applied if the threshold is exceeded. Two arbitrary thresholds were used - 1 C.E. per square metre if cleavers, wild-oat or black-grass were present and 5 C.E. per square metre if they were not. Although ideally threshold values should be adjusted to suit individual crops and seasons, this standard technique had the advantage of ensuring a uniform approach to threshold treatments at all experimental sites. Choice of herbicide was left to local managers, but autumn insurance treatments were generally based on diflufenican plus isoproturon, while later autumn treatments relied on combinations of isoproturon, ioxynil, bromoxynil and mecoprop. Spring treatments usually involved sulfonylurea herbicides or fluroxypyr, with or without the addition of mecoprop. Experimental regimes were applied every year except when break crops occurred. These were given comprehensive overall weed control, so as not to interfere with the development of responses to the cereal herbicide regimes.

4.2.4.2 Weed and Crop Responses

All sites had been in intensive arable production for many years and were chosen as being not particularly weedy. Nevertheless, weed thresholds were exceeded much more often than not. Overall, threshold treatments were applied on 75% of possible occasions in the first four years. In the fifth year (1991-92) they were triggered on every possible occasion (D.H.K. Davies and M. Proven, personal communication). Under all the regimes tested, the levels of weed control achieved by herbicides over the years were commercially acceptable at both normal and half rates, except at the SAC Smith's site, where fluroxypyr, especially at the half rate, could not cope with a dense population of common chickweed on threshold treatments in the second winter barley crop.

Over the first four years of these experiments there were no statistically significant differences in grain yields between any of the herbicide regimes applied at any site and there was no evidence of any trends. The levels of weed control attained were always sufficient to avoid competition with crops. Harvest records from plots untreated with herbicides over the years in the SAC series showed that at three sites it was not until the fourth crop that weed numbers had built up to a level at which yield losses of 10% were obtained. At the Smith's site unrestricted growth by common chickweed reduced yields slightly in the first two years but by over 50% in the third year in comparison with those on full insurance, normal rate plots. This site had a break crop in the fourth year. There were no significant yield losses on untreated plots at the QUB site in the first three cereal crops, which were followed by a break crop of potatoes.

In general, pre-harvest desiccation with glyphosate improved combine through-put at the SAC sites by reducing straw and weed weights at harvest, but had little beneficial effect on grain moisture content or yield.

4.2.5 METHODS AND MATERIALS

Soil samples (2.5 cm cores to 20 cm depth) were taken from each plot after harvesting the fourth crop at each site. At the SAC sites, 20 cores were taken at random across the whole plot; at the other sites, where the plots were longer, 7 cores were taken from each of three sub-plots. Samples from each plot or sub-plot were bulked, mixed thoroughly and deep-frozen at -20°C until required for analysis. After thawing and further mixing, three 200 ml sub-samples were analysed from each SAC plot and one 200 ml sub-sample from each of the three sub-plots at the other sites. Seeds were extracted by sieving and flotation using a Fritsch Analysette (Wilson & Lawson, 1992) and viable seeds were identified and counted.

Seed data from sub-samples were subjected to analysis of variance after square root transformation. The data were co-varied on earlier records collected from soil samples taken in a similar manner prior to sowing the first crop, in order to remove effects of initial variability between plots. In Tables 4.2.1-4.2.9 seed data are shown (after detransformation) as numbers of seeds per square metre (to 20 cm depth) for ease of presentation and to allow comparison with weed seedling counts. The general mean of seed counts taken at the start of the experiment is also given. Total seed counts per square metre do not equate exactly with the sum of individual species means because of the effect of covariance on the data. Total seed numbers per sub-sample are shown at the right of each table, together with standard errors. Total seedling counts per square metre, taken by field staff prior to treatment of the third crops at the SAC and QUB sites and on areas protected from herbicide treatment in the fourth crops at ADAS sites, are presented (Tables 4.2.12 and 4.2.13) to illustrate the cumulative effects of earlier treatments on weed numbers in those crops. Seedling counts were also analysed after square root transformation.

4.2.6 RESULTS SEEDBANK CHANGES

4.2.6.1. Untreated Plots

On plots where neither herbicide treatments nor pre-harvest desiccants had been applied at the SAC sites there were considerable increases in total seed numbers after four years (Table 4.2.1-4.2.4). This was due largely to major increases in seed populations of common chickweed. The reaction of meadow-grasses varied between sites, but seedbanks of brassica species (mainly charlock) and of forget-me-not also increased considerably at Niddrie Mains and Remote respectively. Most other species showed little change or declined in numbers. Overall seed return was considerably in excess of the loss of seeds by seedling production or by natural wastage. At the Strangford site the opposite applied (Table 4.2.5), with a substantial decline in numbers of seeds of the major species and only minor increases in other species including common chickweed. Untreated plots were much less weedy after four years than at the SAC sites, despite having started the series with by far the biggest seedbank.

4.2.6.2 Pre-harvest Desiccation

Annual application of glyphosate before harvest reduced seedbank expansion on plots given no herbicide treatments at Remote, Gleghornie and Niddrie Mains (Tables 4.2.1-4.2.3). The main species affected was common chickweed, although several other species showed similar trends. At Smith's, by contrast, the very large seedbanks of common chickweed on these plots were unaffected by pre-harvest desiccants, although a few other species appeared to respond (Table 4.2.4). The first three crops at the Smith's site were all winter barley, which is sown in early autumn. By harvest time, plants of common chickweed on otherwise untreated plots had largely senesced and would not have responded to a desiccation treatment. Effects of glyphosate on plots treated with herbicides varied considerably, depending primarily on whether or not actively-growing weeds were present at the time of treatment. No consistent benefit could be detected other than for common chickweed at Smith's, where herbicide treatment may have delayed growth and hence the onset of senescence.

4.2.6.3 Herbicide Regimes

In comparison with untreated control plots all the herbicide treatments applied at the SAC sites prevented seedbank populations from achieving major expansion, although not necessarily keeping them below the levels present at the start of the series (Tables 4.2.1-4.2.4). There were, however, substantial increases over the four-year period in seed populations of common chickweed at Remote and Smith's and of brassica species (mainly charlock) at Niddrie Mains despite herbicide treatment. Populations of forget-me-not and knotgrass at Niddrie Mains and of fat-hen and knotgrass at Smith's had declined considerably on treated plots. There was little evidence of differences between untreated and treated plots at Strangford (Table 4.2.5). Seed populations of redshank and meadow-grasses had declined markedly, while those of several less common species had increased. At the ADAS sites (Tables 4.2.6-4.2.9), where there were no untreated plots, the only evidence of generally increasing populations over the four-year period was with field pansy at Gleadthorpe. Substantial reductions were recorded in populations of most species at Drayton, of field pansy at Bridgets and of fat-hen and common chickweed at Rosemaund.

Analysis of seedbank data on individual or total weed species at each site showed relatively few instances of significant differences between herbicide treatments. However, when total counts were pooled and compared across sites, clear trends emerged. Full insurance regimes regularly produced slightly lower seedbank populations than threshold regimes over the four-year period (Table 4.2.10). There were no clear differences between the autumn and grass insurance regimes at the ADAS and QUB sites, but in most cases they both produced higher seedbanks than were found with associated full insurance or threshold regimes. It was also common for there to be higher total numbers of seeds on half-dose than on normal-dose plots (Table 4.2.11). There was no evidence of any interaction between herbicide regime and dose at any of the sites.

4.2.6.4 Weed Seedling Populations

Since the sites at Smith's and Strangford were planted with break crops in the fourth year, weed counts taken in the third crop, before that year's spray treatments were applied, are used to illustrate the cumulative effects of earlier treatments across the SAC and QUB sites (Table 4.2.12). Total seedling numbers were much lower on full insurance plots than on untreated plots; threshold plots were as weedy as untreated plots, except at Niddrie Mains. There was little difference between normal and half rate treatments. Common chickweed was a major part of the flora at all SAC sites and virtually the only species at Smith's. Other important species included meadow-grasses at Remote and Gleghornie, knotgrass at Remote and charlock and forget-me-not at Niddrie Mains. At Strangford the principal weed was redshank, followed by scarlet pimpernel and meadow-grasses. Seedling numbers in the SAC crops showed no clear response to earlier pre-harvest applications of glyphosate and the data are not presented here.

Weed counts made in late spring in the fourth crop at the ADAS sites, on quadrats protected from herbicide treatments in that year, also demonstrated cumulative effects of treatments in previous crops (Table 4.2.13). Differences were not often statistically significant, but on the great majority of plots there were more weeds where half doses had been applied than where normal doses had been used, regardless of the herbicide regime. Averaged across the four sites Full insurance treatments had the fewest and threshold treatments the most weeds, while the autumn and grass insurance treatments were intermediate. The latter regimes were relatively more effective at Gleadthorpe and Rosemaund than at the other two sites. Fool's parsley dominated the flora at Drayton, followed by brassica species and scarlet pimpernel; field pansy made up over 90% of the weeds counted at Bridgets and this species was also dominant at Gleadthorpe, although common chickweed and meadow-grasses were also important; meadow-grasses, followed by common chickweed were the main weeds recorded at Rosemaund.

4.2.7 DISCUSSION

There are compelling reasons in favour of trying to reduce herbicide usage in cereals, but farmers are understandably concerned that the potential cost of **not** controlling weeds may be very much greater than any savings in herbicide costs. How best can the benefits of reduced inputs be gained without taking unnecessary risks or incurring additional costs? The results of our seedbank research, backed up by weed seedling counts, give a clear indication of the likely longer-term effects of the various strategies evaluated.

It took three years without herbicide treatment to transform relatively low seedbank populations at three SAC sites into ones capable of contributing to substantial crop yield reductions; at the initially weedier Smith's site it needed only two years. By contrast, the seedbank at Strangford declined substantially over the first four years and caused no losses in yield. These differences can be attributed largely to the initial species composition of the seedbank and to the cropping sequences used. Species such as common chickweed and meadow-grasses can germinate equally well following autumn or spring seedbed preparation and can thus exploit the absence of weed control in any cereal crop. Species such as redshank and knotgrass which germinate principally in spring, will thrive in untreated spring crops, but may produce few if any seedlings in untreated autumn-sown crops. The changes in seedbank populations over the four years therefore reflect two opposing factors. The first is the natural decline in seed numbers in the soil over the years, which can amount to up to 50% per annum (Wilson & Lawson, 1992), together with any losses due to seedling production in suitable crops. The second is the increase due to successful seed return by uncontrolled weeds. Every site was unique in this respect and the interactions between seed loss and seed return influenced treated as well as untreated plots. The principal components of the seedbank assessed after the fourth crop agreed fairly closely with the main species recorded in the weed seedling counts in the third and fourth crops, after allowing for whether these were spring or autumn sown. Careful choice of autumn or spring crops could delay seedbank expansion in untreated fields, if the species composition of the seedbank were known. Nevertheless, trying to reduce herbicide inputs simply by not treating cereal crops for a few years risks the creation of long-term problems which may require many years of very effective and probably expensive weed control to remedy. The use of reduced rate or threshold strategies offers the chance to manage seedbank populations positively rather than gamble with them.

With one exception, all the herbicide regimes and doses tested over the four year period performed well, with no yield penalty and without causing unacceptable weed problems or a major increase in soil seedbanks. In comparison with the size of initial seedbanks at several sites and the increases recorded on untreated plots at SAC sites, the differences in seedbank populations after four years between the Full insurance regime at normal rates and the other treatments evaluated, although important, were relatively small. In terms of risk, only at the Smith's site did a weed control strategy fail and then only with the threshold regime. The nine sites covered several cereal crops and sequences and a wide range of locations, spraying conditions and weed associations, but gave reasonably consistent results. The general conclusion must therefore be that for most situations all of the reduced input options tested are capable of meeting farmers' requirements, over the medium term. However, these were all initially fairly clean sites and weedier fields would be likely to put more stress on such treatments. Also, there were clear trends in seed and weed populations after several years which suggested that some treatments would be more robust than others over the longer term.

The full insurance regime applied at normal rates every year gave the best performance overall in terms of weed control and seedbank populations. Recommended rates of herbicides include a certain amount of insurance for reliable performance, a) in adverse environmental conditions, b) against less susceptible weeds and c) if the product is used alone rather than as part of a program. Using lower than recommended rates removes any liability which the manufacturer may have for poor weed control. However, under good conditions, with accurate application at the optimum timing, using herbicides with a suitable weed control spectrum, there ought to be scope for reducing rates. Our results have shown that halving the rate gave acceptable weed control without yield penalty over four years.

Although it permitted more weed seed return to the soil, as indicated by slightly higher weed seedbanks and greater weed seedling numbers in later crops, this was not at a level which need cause concern in the medium term. The risk would therefore appear to be acceptable on well-managed farms. This should not be taken as a recommendation for the blanket use of half rates. Where problem weeds are present and very high levels of control are required, even full rates may not give adequate results. Equally, half rates may be too high in some situations. SAC (with HGCA funding) are currently examining responses by weeds to as little as one-eighth of recommended rates of cereal herbicides (Whiting *et al.*, 1990). Their results to date show that it may be possible to design "appropriate" doses of herbicides for particular situations. Amongst other things, this work has produced several instances of herbicide injury in relatively non-weedy crops treated with recommended rates of herbicides - another possible benefit from reducing rates. Until research on "appropriate" doses has progressed further, regular use of half rates of full insurance treatments appear to offer considerable savings in herbicide inputs without appreciable drawbacks and with minimal alteration to current management. This approach also makes the best use of herbicides with pre-emergence activity on weeds. In winter crops there is always the opportunity to remedy any deficiencies in herbicide performance in autumn by a more comprehensive treatment in spring. Careful monitoring of fields will alert farmers to situations where conditions make it more sensible to revert to full rate treatment.

The threshold concept has been adopted successfully for many agricultural pests and diseases. It is more difficult, however, to apply this concept to mixed populations of weeds competing with each other and with the crop and to assess the long-term consequences. In these experiments plots were assessed once only and a spray/no spray decision was made, usually involving the same herbicides as were used on full insurance plots. Current threshold assessment techniques involve counting weeds and the time and labour required imposes a substantial additional cost on crop management every year (Jones, 1990), whether or not the field is actually sprayed. Simpler, cheaper techniques are being sought.

Thresholds were triggered on 75% of occasions in these experiments, so that the potential for savings in herbicide usage with normal rate treatment was limited. On initially weedier fields there might have been none. Raising threshold levels to decrease the frequency of triggering of spray treatment would have risked even higher populations in future years. At the SAC Smith's site thresholds were not triggered in the first year's winter barley crop by populations of common chickweed which went on to produce a massive increase in seedbank populations. It may be that a higher C.E. value is required for common chickweed in early-sown crops, at least under Scottish conditions. Poor control of very large numbers of seedlings of common chickweed by threshold treatments with fluroxypyr in late winter in the second winter barley crop at that site forced the virtual abandonment of the threshold regime thereafter (Lawson *et al.*, 1992). By contrast the full insurance, half rate treatment in October with diflufenican plus isoproturon was very effective. This site illustrates the penalty for making wrong decisions, for whatever reason, about an important weed species and the benefits of early treatment with a prophylactic herbicide.

On the basis of minimising the risks of increasing weed populations, the normal rate threshold treatment was on average poorer at the SAC sites and insufficiently better at the other sites to justify its use in preference to half rates of full insurance treatment. It also reduced herbicide usage and costs by considerably less. Half-rate threshold treatments, although offering greater financial savings, were even less attractive from the weed control aspect, particularly at Smith's. If, as indicated in the fifth crops, thresholds become triggered more frequently as the experiments proceed, this will further diminish the value of the savings from threshold regimes. The intermediate regimes, also utilising thresholds, left larger seedbanks after four years than either of the two alternative regimes at ADAS and QUB sites. Thresholds were not triggered as frequently in spring on these plots as on those managed solely by threshold assessment. Overall, there appeared to be no risk benefit in favour of these regimes in comparison with half rate full insurance treatment.

Regular pre-harvest use of glyphosate reduced the seedbank build-up on untreated plots at three SAC sites. However, seedbanks will only be influenced by this treatment if actively growing weeds are present at harvest and this is less likely if herbicide treatments have been effective. Desiccation would be more appropriately used as a rescue operation to improve harvest efficiency and limit viable seed return in years where reduced herbicide input regimes fail to give the desired results.

4.2.8 CONCLUSIONS

The evidence from these experiments favours the reduction of herbicide inputs by applying fully comprehensive herbicide treatments every year in a prophylactic manner but at reduced rates, in preference to any of the threshold approaches tested. Effects to date on seedbank and weed seedling populations suggest that this will be more sustainable over the longer term. However, there is considerable potential for further research to aid the choice of the most appropriate herbicide and dose for reduced rate treatments in a wide range of situations, possibly involving the use of simplified threshold assessments. This should help scientists to design more effective and finely-tuned weed control strategies for cereal producers, which could reduce herbicide inputs still further.

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Table 4.2.1 Seedbank assessment after four crops - SAC Remote

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Glyphosate	Common chickweed	Meadow-grasses	Fumitory	Forget-me-not	Total	(T)†
Untreated	-	11400	3527	0	566	16115	(6.98)
	+	8477	1066	0	0	9487	(5.37)
Full insurance normal dose	-	94	635	94	73	1303	(2.07)
	+	94	58	151	127	355	(1.20)
Full insurance half dose	-	438	1345	363	73	2359	(2.73)
	+	133	908	20	0	1182	(1.98)
Threshold option normal dose	-	447	1016	0	73	1700	(2.34)
	+	293	492	182	0	1156	(1.96)
Threshold option half dose	-	557	208	16	0	873	(1.73)
	+	1235	1091	34	29	2956	(3.04)
S.E. mean ±							(0.618)
General mean before first crop		22	1577	267	33	2300	

† Total live seeds recovered from 600 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance.

Table 4.2.2 Seedbank assesment after four crops - SAC Gleghornie

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Glyphosate	Common chickweed	Meadow-grasses	Fat-hen	Knotgrass	Total	(T)†
Untreated	-	14704	805	3	3	16489	(7.06)
	+	1925	2163	0	0	4291	(3.64)
Full insurance normal dose	-	105	438	0	0	739	(1.61)
	+	492	772	0	3	1317	(2.08)
Full insurance half dose	-	666	884	0	0	1638	(2.30)
	+	388	586	94	0	1518	(2.22)
Threshold option normal dose	-	676	739	0	0	1942	(2.49)
	+	2470	1518	0	3	4488	(3.72)
Threshold option half dose	-	482	2451	0	202	3204	(3.16)
	+	2128	2564	0	3	5397	(4.07)
S.E. mean ±							(0.960)
General mean before first crop		910	1200	134	110	2982	

† Total live seeds recovered from 600 ml soil, after transformation ($\sqrt{x}$ + 0.375) and co-variance.

Table 4.2.3 Seedbank assessment after four crops - SAC Niddrie Mains

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Glyphosate	Common chickweed	Brassica species	Forget-me-not	Meadow-grasses	Black bindweed	Knotgrass	Total	(T)†
Untreated	-	13785	1387	1117	88	278	0	20889	(7.94)
	+	7238	605	1041	438	0	3	11597	(5.93)
Full insurance normal dose	-	0	324	25	88	3	88	538	(1.41)
	+	316	58	12	0	94	0	838	(1.70)
Full insurance half dose	-	0	576	0	88	202	229	1843	(2.43)
	+	43	58	48	88	0	0	465	(1.33)
Threshold option normal dose	-	557	242	3	0	0	0	1276	(2.05)
	+	615	1700	0	163	278	99	3396	(3.25)
Threshold option half dose	-	116	308	0	3	371	0	2915	(3.02)
	+	3	331	12	0	88	250	1967	(1.81)
S.E. mean ±									(0.812)
General mean before first crop		590	33	1123	134	210	757	5433	

† Total live seeds recovered from 600 ml soil, after transformation ($\sqrt{x}$ + 0.375)) and co-variance

Table 4.2.4 Seedbank assessment after four crops - SAC Smith's

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Glyphosate	Common chickweed	Meadow-grasses	Fat-hen	Knotgrass	Total	(T)†
Untreated	-	32611	955	1593	635	35582	(10.35)
	+	35238	195	1053	189	35307	(10.31)
Full insurance	-	5397	0	1843	761	9739	(5.44)
normal dose	+	1942	0	861	170	2251	(2.67)
Full insurance	-	3461	0	293	157	4195	(3.60)
half dose	+	2094	78	872	43	4389	(3.68)
Threshold option	-	4714	308	355	0	5671	(4.17)
normal dose	+	2359	718	229	264	4005	(3.52)
Threshold option	-	7555	68	379	176	9776	(5.45)
half dose	+	5811	510	301	421	7651	(4.83)
S.E. mean ±							(0.895)
General mean before first crop		157	422	4933	1967	9117	

† Total live seeds recovered from 600 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance.

Table 4.2.5 Seedbank assessment after four crops - QUB Strangford

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Dose	Redshank	Meadow-grasses	Common chickweed	Knotgrass	Black bindweed	Scarlet pimpernel	Total	(T)†
Untreated		1213	1238	625	249	173	203	7078	(2.73)
Full insurance	Normal	813	281	281	605	74	770	3787	(2.04)
	Half	770	0	749	365	625	314	3506	(1.97)
Autumn insurance	Normal	1670	728	365	331	233	490	4334	(2.17)
	Half	749	645	281	365	188	74	2653	(1.74)
Grass insurance	Normal	1263	331	813	218	791	314	5242	(2.37)
	Half	2653	686	1089	645	417	435	6969	(2.71)
Threshold option	Normal	1529	1163	453	115	74	188	5875	(2.50)
	Half	365	1065	453	365	0	605	3159	(1.88)
S.E. mean ±									(0.380)
General mean before first crop		8975	4926	111	741	62	37	19715	

† Total live seeds recovered from 200 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance

Table 4.2.6 Seedbank assessment after four crops - ADAS Drayton

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Dose	Fool's parsley	Brassica species	Scarlet pimpernel	Knotgrass	Black bindweed	Total	(T)†
Full insurance	Normal	971	665	218	158	0	2057	(1.56)
	Half	835	707	249	365	203	2282	(1.63)
Autumn insurance	Normal	1421	1163	115	471	173	4334	(2.17)
	Half	1138	902	314	158	115	3311	(1.92)
Grass insurance	Normal	528	835	994	74	158	3085	(1.86)
	Half	173	749	879	48	249	2618	(1.73)
Threshold option	Normal	749	1341	87	61	35	2249	(1.68)
	Half	749	1502	281	265	87	2937	(1.82)
S.E. mean ±								(0.161)
General mean before first crop		5150	6240	1390	444	292	14405	

† Total live seeds recovered from 200 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance

Table 4.2.7 Seedbank assessment after four crops - ADAS Gleadthorpe

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Dose	Common chickweed	Field pansy	Meadow-grasses	Brassica species	Total	(T)†
Full insurance	Normal	218	314	0	143	1613	(1.41)
	Half	348	399	471	115	1488	(1.35)
Autumn insurance	Normal	791	1289	61	61	2414	(1.67)
	Half	1041	707	218	115	2723	(1.76)
Grass insurance	Normal	471	1065	314	265	2723	(1.76)
	Half	925	509	129	0	3011	(1.84)
Threshold option	Normal	365	1213	158	265	2121	(1.58)
	Half	314	948	453	173	1997	(1.54)
S.E. mean ±							(0.250)
General mean before first crop		417	222	681	111	1952	

† Total live seeds recovered from 200 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance

Table 4.2.8 Seedbank assessment after four crops - ADAS Bridgets

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Dose	Field pansy	Ivy-leaved speedwell	Meadow-grasses	Corn spurrey	Total	(T)†
Full insurance	Normal	5385	129	22	0	5195	(2.36)
	Half	7862	74	61	87	8745	(3.02)
Autumn insurance	Normal	8093	48	61	0	9050	(3.07)
	Half	10383	265	22	143	11735	(3.48)
Grass insurance	Normal	8328	173	101	87	9359	(3.12)
	Half	11945	87	22	0	12370	(3.57)
Threshold option	Normal	5481	74	22	0	5628	(2.45)
	Half	8387	143	22	0	8806	(3.03)
S.E. mean ±							(0.366)
General mean before first crop		38300	403	56	14	40079	

† Total live seeds recovered from 200 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance

Table 4.2.9 Seedbank assessment after four crops - ADAS Rosemaund

Live seeds recovered/m^2 (to 20 cm depth) - main species

Herbicide regime	Dose	Meadow-grasses	Fat-hen	Shepherd's purse	Common chickweed	Total	(T)†
Full insurance	Normal	2829	218	218	87	4509	(2.21)
	Half	3951	265	74	0	5054	(2.33)
Autumn insurance	Normal	1905	9	9	0	2414	(1.67)
	Half	8625	173	87	0	8989	(3.06)
Grass insurance	Normal	2315	101	87	0	2447	(1.68)
	Half	3828	0	0	331	4291	(2.16)
Threshold option	Normal	3545	233	0	0	3993	(2.09)
	Half	5433	74	9	0	5443	(2.41)
S.E. mean ±							(0.301)
General mean before first crop		3084	1444	222	1069	9445	

† Total live seeds recovered from 200 ml soil, after transformation ($\sqrt{x} + 0.375$) and co-variance

Table 4.2.10 Seed counts taken after four crops - Effects of different herbicide regimes

	Total seeds (1000)/m^2 (to 20 cm depth)			
	Full insurance	Threshold option	Autumn insurance	Grass insurance
SAC sites				
Remote	1.30	1.67	-	-
Gleghornie	1.30	3.76	-	-
Niddrie Mains	0.92	2.39	-	-
Smith's	5.14	6.78	-	-
ADAS sites				
Drayton	2.17	2.59	3.82	2.85
Gleadthorpe	1.53	2.06	2.57	2.87
Rosemaund	4.78	4.71	5.70	3.37
Bridgets	6.97	7.22	10.39	10.86
QUB site				
Strangford	3.65	4.52	3.49	6.11

Table 4.2.11 Seed counts taken after four crops - Effects of normal or half dose herbicide treatments

	Total seeds (1000)/m^2 (to 20 cm depth)	
	Normal dose	Half dose
SAC sites		
Remote	1.13	1.84
Gleghornie	2.12	2.94
Niddrie Mains	1.51	1.80
Smith's	5.42	6.50
ADAS sites		
Drayton	2.93	2.79
Gleadthorpe	2.22	2.30
Rosemaund	3.34	5.94
Bridgets	7.31	10.41
QUB site		
Strangford	4.81	4.07

Table 4.2.12 Weed counts taken in the third crop prior to herbicide treatment (SAC and QUB sites)

Herbicide regime	Dose	Total weed numbers/m^2				
		Remote	Gleghornie	Niddrie Mains	Smith's†	Strangford
Full insurance	Normal	4 (2.1)	9 (3.1)	26 (5.1)	12 (3.5)	38 (6.2)
	Half	2 (1.5)	10 (3.2)	28 (5.3)	12 (3.5)	41 (6.4)
Threshold option	Normal	18 (4.3)	15 (3.9)	27 (5.2)	126 (11.2)	82 (9.1)
	Half	19 (4.4)	18 (4.3)	36 (6.1)	140 (11.9)	66 (8.2)
Untreated		16 (4.1)	17 (4.1)	58 (7.7)	104 (10.2)	61 (7.8)
S.E. mean ±		(0.61)	(0.21)	(0.28)	(1.20)	(1.07)

Figures in parenthesis are numbers/m^2 after transformation ($\sqrt{x + 0.375}$) for statistical analysis.
† Common chickweed only.

Table 4.2.13 Weed counts taken late in the fourth crop in areas protected from all herbicide treatments in that year (ADAS sites)

Herbicide regime	Dose	Total weed numbers/m^2			
		Drayton	Gleadthorpe	Rosemaund	Bridgets
Full insurance	Normal	102 (10.1)	82 (9.1)	72 (8.5)	132 (11.5)
	Half	137 (11.7)	112 (10.6)	97 (9.9)	163 (12.8)
Autumn insurance	Normal	158 (12.6)	94 (9.7)	60 (7.8)	179 (13.4)
	Half	130 (11.4)	74 (8.6)	86 (9.3)	182 (13.5)
Grass insurance	Normal	123 (11.1)	100 (10.0)	93 (9.7)	171 (13.1)
	Half	198 (14.1)	106 (10.3)	113 (10.6)	216 (14.7)
Threshold option	Normal	127 (11.3)	110 (10.5)	95 (9.8)	171 (13.1)
	Half	144 (12.0)	154 (12.4)	86 (9.3)	259 (16.1)
S.E. mean ±		(1.07)	(1.33)	(0.48)	(0.63)

Figures in parenthesis are numbers/m^2 after transformation ($\sqrt{x + 0.375}$) for statistical analysis.

Table 4.2.14 Overall effects of full insurance and threshold option regimes on seed populations after four crops

Total seeds (1000)/m^2 (to 20 cm depth)					
	Full insurance		Threshold option		Mean original Populations
Mean of	Normal dose	Half dose	Normal dose	Half dose	1987-88
SAC sites	2.14	2.20	2.95	4.34	4.96
ADAS & QUB sites	3.43	4.21	3.97	4.47	17.12

PART 1 APPENDIX

CROP EQUIVALENT TESTING AND HERBICIDE RESPONSES

Assessment of factors influencing crop equivalent values; QUB

Table 1 Sitedetails

Site Address	ARMOY Co Antrim, NI Warwickshire	GREENMOUNT Co Antrim, NI	HILLSBOROUGH Co Down, NI	LOUGHGALL Co Down, NI	GLEADTHORP Nottinghamshire	L A R S Avon	DRAYTON
Soil type	Peat	Organic clay loam	Loamy sand	Organic sandy loam	Loamy sand	Clay loam	Organic clay
CV	Galahad	Galahad	Galahad	Galahad	Mercia	Avalon	-
Drilling date	4.11.87	2.11.87	3.10.87	5.11.87	23. 9.87	29. 9.87	30. 9.87
Weeds sown	15.11.87	15.11.87	19.11.87	19.11.87	16.10.87	16.10.87	15.10.87
Background weed	3. 2.88	3. 2.88	4. 2.88	4. 2.88			
Weed & crop manipulation	30. 3.88	25. 3.88	16. 3.88	31. 3.88	10. 3.88	9. 3.88	8. 3.88
1st harvest	5. 5.88	28. 4.88	28. 4.88	29. 4.88	19. 4.88	20. 4.88	19. 4.88
2nd harvest	20. 6.88	20. 6.88	21. 6.88	20. 6.88	9. 6.88	8. 6.88	9. 6.88
3rd harvest	30. 8.88	15. 8.88	15. 8.88	23. 8.88	2. 8.88	3. 8.88	2. 8.88
Crop density m^2	284	302	252	240	218	200	212
Weed density m^2							
Cleavers	4	4	3	4	4	4	4
Chickweed	24	24	15	25	7	25	24
Annual meadow-grass	160	140	72	158	113	148	88

Table 1 Site details (continued)

Site Address	ARTHUR RICKWOOD Cambridgeshire	DRAYTON Warwickshire	HILLSBOROUGH Co Down, NI	GLEADTHORPE Nottinghamshire
Soil type	Peaty clay	Organic clay	Loamy sand	Loamy sand
CV		Avalon	Slejpner	Slejpner
Drilling date			28.10.88	23. 9.88
Weeds sown	20.10.88	20.10.88	4.11.88	19.10.88
Background weed	13.12.88	13.12.88	10. 1.89	15.12.88
Weed and crop manipulation	28. 2.89	1. 3.89	7. 3.89	1. 3.89
1st harvest	26. 4.89	27. 4.89	9. 5.89	26. 4.89
2nd harvest	20. 6.89	21. 6.89	29. 6.89	20. 6.89
3rd harvest	1. 8.89	1. 8.89	9. 8.89	2. 8.89
Crop density/m^2	179	222	315	208
Weed density/m^2				
Cleavers	4	4	4	4
Chickweed	25	25	25	25

CROP DENSITY HERBICIDE EFFICACY INVESTIGATIONS

Experiment 1, 1990.

The Significance of Crop Density on Herbicide Efficacy in Spring barley.

This experiment was carried out at the Agricultural Research Institute, N. Ireland. The spring barley (cv Prisma) was sown 21st March 1990 at a range of seeding densities (0, 50, 100, 200, 400 m^2). The herbicide metsulfuron-methyl (Ally, Dupont U.K. Ltd.) was applied 17th May at 0, 0.25, 0.5, 1.0 normal rates of application (30g/ha). The individual weed species biomass, was assessed on the basis of two 0.5 m^2 quadrats taken in July. The plots 2 m x 20 m were combined for grain yield.

RESULTS SUMMARY TABLES

Table 2

(a) Grain yield T/Ha

Seed Rate (SR)	Herbicide Rate (HR)			
	0	0.25	0.5	1
0	-	-		-
50	3.48	4.02	3.88	4.16
100	4.26	4.83	4.52	4.98
200	5.46	5.42	5.25	5.92
400	5.14	6.33	5.51	5.92

	DF	SIG	SE^+
SR	4	***	0.12
HR	3	**	0.11
SR X HR	12	NS	0.25

(b) Broad-leaved weed DM

Seed Rate (SR)	Herbicide Rate (HR)			
	0	0.25	0.5	1
0	613	156	63	35
50	194	20	31	1
100	259	54	3	1
200	372	10	0	1
400	143	0	8	2
	DF	SIG	SE+	
SR	4	***	29.8	
HR	3	***	26.6	
SR X HR	12	*	59.6	

(c) Poa DM

Seed Rate (SR)	Herbicide Rate (HR)			
	0	0.25	0.5	1
0	145	751	659	549
50	196	262	181	175
100	56	138	182	102
200	42	68	77	144
400	25	28	113	41
	DF	SIG	SE+	
SR	4	***	38.5	
HR	3	**	34.5	
SR X HR	12	*	77.1	

(d) BLW + Poa DM

Seed Rate (SR)	Herbicide Rate (HR)			
	0	0.25	0.5	1
0	759	906	721	584
50	390	282	212	176
100	315	193	186	103
200	414	78	78	144
400	168	28	121	43
	DF	SIG	SE+	
SR	4	***	40.1	
HR	3	**	35.9	
SR X HR	12	NS	80.2	

CROP DENSITY HERBICIDE EFFICACY INVESTIGATIONS

Experiment 2.

The Significance of Crop Density on Herbicide Efficacy in Winter Wheat.

The experiment was conducted at a farm site at the Maze, Co. Antrim, N. Ireland in 1989. The winter wheat (cv Appollo) was sown 23/10/89 at a range of seed rates nil, 40, 80, 120, 240, 480 seeds m^2. The herbicide regime consisted of Diflufenican/IPU (Couger Rhone Poulenc) at 0, $^1/_8$, $^1/_4$, $^1/_2$, and normal rate (2.0 l/ha) in the autumn (10/11/90), followed in the spring (27/4/90), by Metsulfuron-methyl (Ally Dupont) at the same range of rates as the initial autumn application. The experiment was fully randomised with four blocks with individual plots 4x20 m. A series of crop and weed assessments were made and combine yields obtained at harvest.

Table 3

(a) Grain yield T/Ha

Seed Rate (SR)	Herbicide Rate (HR)				
	0	0.125	0.25	0.5	1
0	0	0	0	0	0
40	3.44	4.55	4.07	4.45	4.22
80	3.9	5.22	5.08	4.71	5.0
120	4.6	5.24	5.4	5.58	5.59
240	4.79	5.25	5.37	5.28	5.89
480	3.87	5.0	4.39	4.66	4.83

	DF	SIG	SE^+
SR	5	***	0.13
HR	4	***	0.12
SR X HR	20	NS	0.29

BLW DM 15/6/90

Seed Rate (SR)	Herbicide Rate (HR)				
	0	0.125	0.25	0.5	1
0	648.1	307.9	201.6	54.5	32.0
40	225.6	51.9	51.2	26.2	9.2
80	238.4	35.9	15.4	8.1	13.2
120	159.5	17.3	9.0	5.4	4.7
240	97.5	9.7	4.8	2.8	16.5
480	89.2	5.4	5.0	0	0

	DF	SIG	SE^{+}
SR	5	***	17.5
HR	4	***	15.9
SR X HR	20	***	39.1

Elymus repens DM 15/6/90

Seed Rate (SR)	Herbicide Rate (HR)				
	0	0.125	0.25	0.5	1
0	88	264	355	357	327
40	178	84	143	95	78
80	138	175	93	224	102
120	17	70	70	42	59
240	14	124	15	20	11
480	14	8	35	24	7

	DF	SIG	SE^{+}
SR	5	***	25.4
HR	4	NS	23.2
SR X HR	20	NS	56.9

WEED DENSITY EFFECTS ON HERBICIDE EFFICACY AND YIELD RESPONSE IN SPRING BARLEY.

Experiment 1.

A Simulation Study with Oilseed Rape to Define Weed Density Effects on Herbicide Efficacy and Yield Response in Spring Barley.

In 1989 at a farm site in Co. Down, oilseed rape was broadcast into a spring barley crop at three rates - zero, medium and high giving 0, 97 and 351 plants per m^2. There was a very low background weed population (24 m^2), mainly red dead-nettle. Three herbicides, metsulfuron-methyl (Ally, Dupont UK Ltd.), MCPA/dichloroprop (Hemoxone, Plant Protection Ltd.) and Fluroxypyr/HBN (Advance, Plant Protection Ltd.) were applied on 7th June at 0.25, 0.5, 1.0 and 2.0 the normal recommended rates. Biomass samples (0.5 m^2 per plot) were taken on 24 June 1991 and combine yields at harvest.

SUMMARY RESULTS

Table 4

(a) Grain yield T/Ha

	Mean Herbicide Rate (HR)				
OSR Density (D)	0	0.25	0.5	1.0	2.0
High	3.18	3.20	3.50	3.37	3.55
Medium	3.55	3.68	3.72	3.66	3.79
Nil	4.03	3.91	3.95	3.89	3.94

	DF	SIG	SE^{+}
D	2	***	0.07
HR	4	NS	0.09
D X HR	8	NS	0.16

(b) Oilseed rape DM G/m^2 (4 W.A.T.)

OSR Density (D)	Mean Herbicide Rate (HR) 0	0.25	0.5	1.0	2.0
High	187.9	131.0	91.0	76.6	43.5
Medium	86.7	58.0	36.2	32.6	3.7
Nil	11.0	3.7	1.9	1.3	1.8

	DF	SIG	SE$^+$
D	2	***	5.24
HR	4	***	6.77
D X HR	8	*	11.73

(c) Crop DM G/m^2 (4 W.A.T.)

OSR Density (D)	Mean Herbicide Rate (HR) 0	0.25	0.5	1.0	2.0
High	377.5	368.0	460.5	405.7	417.4
Medium	499.3	492.5	560.1	568.4	584.1
Nil	614.0	623.4	607.4	569.9	592.5

	DF	SIG	SE$^+$
D	2	***	13.28
HR	4	NS	17.14
D X HR	8	NS	29.69

Experiment 2.

This experiment, to examine the effect of weed density on herbicide responses was conducted at Greenmount Agricultural College, Co. Antrim during 1991.

Oilseed rape was broadcast on to the spring barley seedbed to give established seedling densities at the time of spraying of 0, 200, 400, 800, 1600 plants per m^2 and a crop stand of 260 plants per m^2 (Table 5). The individual plot size being 2½ x 5 m. The crop was sprayed on 7th June at the developmental stages presented in Table 5. The herbicides metsulfuron-methyl (Ally, Dupont U.K. Ltd.) and MCPA/dichloroprop (Hemoxone, Plant Protection Ltd.) were applied each at 0, 0.5, 1.0 and 2.0 the normal recommended rates. Biomass of crop and weed was assessed in 0.5 m^2 samples taken on 24th July. Combine yields were obtained at harvest and expressed as t/ha at 15% moisture content.

Table 5 OSR density experiment 1991

(a) Crop/OSR details at spraying

OSR Density	Leaf No.	Tiller No.	Nodes	Plants/m^2	
				Barley	OSR
D0 (0)	5.8	4.8	0	272	0
D1 (200)	5.9	3.5	0	292	204
D3 (400)	6.1	3.4	0	276	368
D3 (800)	5.6	1.6	0	232	912
D4 (1600)	5.2	0.8	0	268	1652

(b) Grain yield T/Ha

Metsulfuron-methyl (H)

OSR Density (D)	Herbicide Rate (HR)			
	0	0.5	1.0	2.0
0	4.31	4.18	4.45	4.35
200	2.97	4.66	5.02	3.89
400	3.07	3.66	4.28	4.42
800	2.45	3.40	3.57	4.25
1600	2.14	3.26	3.92	4.38

MCPA/Dicloroprop (H)

OSR Density (D)	Herbicide Rate (HR)			
	0	0.5	1.0	2.0
0	4.31	4.22	4.31	4.65
200	2.97	4.90	4.72	4.46
400	3.07	4.75	4.50	4.88
800	2.45	4.00	4.04	4.85
1600	2.14	4.09	4.03	4.87

		DF	**SIG**	**SE^{+}**
OSR	D	4	***	0.12
	H	1	**	0.10
	HR	2	*	0.12
	D x H	4	NS	0.22
	D x HR	8	NS	0.25
	H x HR	2	NS	0.13
	D x H x HR	8	NS	0.30

(c) OSR DM (4 W.A.T.)

Metsulfuron-methyl (H)

OSR Density (D)	Herbicide Rate (HR)			
	0	0.5	1.0	2.0
0	0	0	0	0
200	236.4	50.1	32.5	36.1
400	223.5	117.5	167.5	79.0
800	371.7	269.8	165.4	120.5
1600	437.9	252.0	235.8	202.4

MCPA/Dicloroprop (H)

OSR Density (D)	Herbicide Rate (HR)			
	0	0.5	1.0	2.0
0	0	0	0	0
200	236.4	15.6	7.5	0.4
400	223.5	7.8	10.7	0.5
800	371.7	48.7	18.7	2.1
1600	437.9	38.9	15.0	3.3

		DF	SIG	SE^{+}
OSR	D	4	***	12.39
	H	1	***	10.12
	HR	2	NS	11.08
	D x H	4	***	22.62
	D x HR	8	NS	24.78
	H x HR	2	NS	13.57
	D x H x HR	8	NS	30.35

PART 2 APPENDIX

FARM TRIALS

Table 1 Sites and treatment

Site	Soil	Crop 1987/88	1988/89	1989/90	1990/1	Treatments
Agricultural Development and Advisory Service(ADAS)						
Bridgets EHF, Winchester	SL	WW	WW	WW	WW	1-8
Drayton EHF Stratford	C	WW	WW	WW	WW	1-8
Gleadthorpe EHF Mansfield	LMS	WW	WW	FB	SW	1-8
Rosemaund EHF Hereford	ZCL	WW	WW	WW	WW	1-8
Cambridge	ZCL	WW	WW	Stopped 1989		1-8
Starcross, Exeter	CL	-	-	-	WW	1-8
The Scottish Agricultural College (SAC) Edinburgh (formerly ESCA)						
Smith's Holding Bush, Edinburgh	SL	WB	WB	WB	SOSR	1,4,5, 8,9,10
J Crichton, Niddrie Mains, W Lothian	CL	WW	WW	SB	WW	1,4,5, 8,9,10
N Paton, Gleghornie E. Lothian	CL	WW	WW	WW	WW	1,4,5, 8,9,10
J Stewart, Remote Midlothian	CL	SB	SB	SB	WW	1,4,5, 8,9,10
The Queen's University of Belfast (QUB)						
J Orr, Strangford Co. Down	SL	WW	WW	SW	POT	1-8,9

Table 2 Crop and thresholds triggered at all sites 1987/8 - 1990/1

Season	1987/8		1988/9		1989/90		1990/1	
Site	**Crop**	**TT**	**Crop**	**TT**	**Crop**	**TT**	**Crop**	**TT**
Bridgets	W	all	W	At	W	all	W	At/Sp
Drayton	W	all	W	Sp	W	At	W	At/Sp
Gleadthorpe	W	At/Sp	W	At/Sp	-	-	SW	Sp
Rosemaund	W	At/Sp	W	At	W	At	W	At/Sp
Cambridge	W	all	W	all	-	-	-	-
S W Region	-	-	-	-	W	all	WO	At/Sp
Strangford	W	Sp	W	X	SW	Sp	-	-
Niddrie Mains	W	Sp	W	X	SB	1/2T	W	At/Sp
Gleghornie	W	Sp	W	X	W	X	W	At
Bush	WB	X	WB	Sp	WB	At	-	-
Remote	SB	X	SB	X	SB	X	W	At

X - No threshold triggered (TT)
Sp - Spring " "
At - Autumn " "
all - All " "

W: winter wheat; SW: spring wheat (autumn sown); SB: spring barley; WB: winter barley; WO: winter oats.

Table 3A Grain yields from herbicide treatments (t/ha @ 85%DM)

ADAS Series - All winter wheat except*

(i) 1988

Rate	Bridgets		Drayton		Gleadthorpe		Rosemaund		Cambridge	
	F	½	F	½	F	½	F	½	F	½
Full Insurance	6.82	6.28	7.68	7.49	5.64	6.18	9.84	9.81	8.1	8.4
Autumn Insurance	5.66	5.90	7.78	7.83	6.03	5.87	9.63	9.14	8.4	8.1
Grass Insurance	6.14	5.81	8.11	8.12	5.67	5.97	9.17	9.26	8.1	8.3
Threshold	5.98	6.21	7.80	7.55	6.28	6.21	9.54	9.83	8.4	8.1

Site (column heading spanning Bridgets–Cambridge)

(ii) 1989

Rate	Bridgets F	Bridgets ½	Drayton F	Drayton ½	Gleadthorpe F	Gleadthorpe ½	Rosemaund F	Rosemaund ½	Cambridge F	Cambridge ½
Full Insurance	7.56	7.83	5.47	5.77	4.67	4.85	6.59	6.23	7.65	7.32
Autumn Insurance	7.18	7.67	5.68	5.83	5.18	4.85	6.49	6.02	7.82	7.42
Grass Insurance	7.38	7.70	5.77	5.73	4.67	5.14	6.41	6.33	7.97	6.97
Threshold	7.76	7.42	5.67	5.51	4.78	4.68	6.23	6.27	7.97	7.73

(iii) 1990

Rate	Bridgets F	Bridgets ½	Drayton F	Drayton ½	Gleadthorpe F	Gleadthorpe ½	Rosemaund F	Rosemaund ½	Cambridge F	Cambridge ½
Full Insurance	7.60	7.18	5.15	5.23	-	-	7.06	6.88	5.24	5.36
Autumn Insurance	6.74	6.32	5.35	5.22	-	-	7.08	7.00	5.21	5.20
Grass Insurance	6.82	6.44	5.44	5.16	-	-	7.18	7.16	4.97	5.06
Threshold	7.47	7.52	5.00	5.40	-	-	7.10	7.02	4.84	5.59

(iv) 1991

Rate	Bridgets F	Bridgets ½	Drayton F	Drayton ½	Gleadthorpe F	Gleadthorpe ½	Rosemaund F	Rosemaund ½	Cambridge F	Cambridge ½
Full Insurance	6.25	6.04	7.10	7.21	6.44	5.90	8.51	8.51	7.48	7.84
Autumn Insurance	6.01	5.55	7.15	7.16	6.44	6.13	8.48	8.57	8.34	8.16
Grass Insurance	6.10	5.55	7.18	7.14	6.05	6.24	8.46	8.59	8.24	8.32
Threshold	6.14	6.05	7.22	7.23	6.34	6.20	8.25	8.46	7.36	7.59

*Gleadthorpe = spring wheat (autumn sown)
*SW = winter oats

Table 3B

SAC Series

a] Spring barley sites

	Year/Site											
	1988		1989		1990		1990		1991			
	Remote		Remote		N. Mains		Remote		N. Mains		All	
	F	½	F	½	F	½	F	½	F	½	F	½
Full Insurance	7.13	7.28	6.27	6.41	7.58	7.47	8.41	8.35	7.36	7.44	7.35	7.39
Threshold	7.35	7.31	6.45	6.38	7.47	7.02	8.49	8.32	7.39	7.59	7.43	7.32
Untreated	7.41		6.52		7.39		8.26		6.51*		7.22	
	NS		NS		NS		NS		S*		NS	

b] Winter wheat sites

i) 1988

	Sites			
	Gleghornie		Niddrie Mains	
	F	½	F	½
Full Insurance	12.31	12.10	9.30	9.36
Threshold	12.40	12.45	9.15	9.27
Untreated	12.25		8.91*	
	NS		S	

(ii) 1989

	F	½	F	½
Full Insurance	10.19	10.15	7.44	7.15
Threshold	10.24	10.09	7.36	7.50
Untreated	9.69		7.88	
	NS		NS	

(iii) 1990 - Gleghornie

	Herbicide Rate	
	F	½
Full Insurance	8.28	9.01
Threshold	8.67	8.99
Untreated	9.45*	
	S*	

(iv) 1991

	Site			
	Gleghornie		Remote	
	F	½	F	½
Full Insurance	7.89	7.99	10.07	9.62
Threshold	8.00	7.91	10.11	9.97
Untreated	7.09*		8.86*	
	S*		S*	

c] Winter barley sites

	Year/Site (all Bush)							
	1988+		1989		1990		All	
	F	½	F	½	F	½	F	½
Full Insurance	7.85	7.07	8.70	8.62	7.12	6.87	7.89	7.52
Threshold	7.47	6.45	8.71	8.10	7.09	6.92	7.76	7.16*
Untreated	7.79		8.23		3.35*		6.45*	
	S**		NS		S*		S*	

+ Untreated = Threshold; variation high due to chickweed distribution.

Table 3C

QUB Series (Strangford)

	Year/Crop/Site (all Strangford)					
	1988		**1989**		**1990**	
	W. Wheat		**W. Wheat**		**S. Wheat** (+)	
	F	**½**	**F**	**½**	**F**	**½**
Full Insurance	10.99	10.88	6.49	6.30	5.67	5.57
Autumn Insurance	10.65	9.92	6.13	7.92	6.00	5.91
Grass Insurance	10.56	10.52	6.71	7.00	5.81	5.48
Threshold	10.82	10.94	6.00	6.60	6.14	5.63
Untreated	10.55		6.25		5.66	
	NS		NS		NS	

(+) Autumn - sown

F = full-rate herbicide when used

½ = half-rate herbicide when used

Table 4 Effect of glyphosate used pre-harvest on % straw dry matter; Scottish sites

Site	Glyphosate +	Glyphosate -	Significance
1988			
Gleghornie (WW)	67.3	61.7	S
Niddrie Mains (WW)	78.7	79.7	NS
Bush (WB)	73.7	67.7	S
Remote (SB)	44.8	43.2	S
1989			
Bush (WB)	75.7	75.5	NS
1990			
Bush (WB)	56.7	47.5	S
1991			
Gleghornie (WW)	65.7	68.6	S
Niddrie Mains (SB)	54.2	54.9	NS
Remote (WW)	79.7	79.4	NS

Out of 9 harvests where the effect of glyphosate pre-harvest was tested, glyphosate significantly increased straw dry matter on five occasions.

Table 5A Effect of treatment on 1000-grain weight (g) and grain specific weight; Scottish sites

Site	N	½N	N	½	Untreated
1988					
Gleghornie	49.3	50.6	49.3	49.8	50.2
Niddrie Mains	39.9	39.5	38.8	39.6	39.8
Bush	39.6	39.4	39.3	39.0	39.3
Remote	52.1	52.2	51.6	51.9	52.5
1989					
Bush	43.6	42.6	45.1	43.9	43.4
Remote	49.8	50.4	49.4	50.8	50.8
1990					
Gleghornie	52.6	52.8	50.7	51.9	51.6
Niddrie Mains	49.9	50.5	50.3	50.7	50.7
Bush	47.6	47.4	48.1	47.4	43.7*
Remote	46.0	45.4	44.9	45.2	43.6*
1991					
Gleghornie	46.5	46.2	46.2	46.3	45.8*
Niddrie Mains	48.0	48.2	48.7	48.5	46.5*
Remote	53.9	53.7	53.0	54.5	54.4
Mean:	47.6	47.6	47.3	47.7	47.1

* Significant differences

There was overall, a slight trend to reduced 1000-grain weight in Untreated plots; most noticeable at the very weedy Bush site in 1990.

Table 5B Effect of glyphosate pre-harvest on 1000-grain weight (g)

	Glyphosate	
Site	+	-
1988		
Gleghornie	50.*	49.2
Niddrie Mains	44.7	45.3
Bush	39.3	39.3
Remote	51.9	52.2
1989		
Bush	44.6	43.5
Remote	49.8	50.7
1990		
Gleghornie	51.5	52.5
Niddrie Mains	50.5	50.7
Bush	46.9	46.8
Remote	44.6	44.9
1991		
Gleghornie	46.3	46.1
Niddrie Mains	47.7	48.2*
Remote	54.7*	53.1
Mean	47.8	48.2

There was a slight overall trend to lower 1000-grain weight when glyphosate was used pre-harvest, but there was no consistent pattern.

Table 5C Effect of treatment on grain specific weight

	N	½N	N	½N	Untreated
1991					
Glenhornie	68.0	68.2	68.7	68.3	68.2
Niddrie Mains	64.0	64.0	64.0	64.2	62.2*
Remote	75.2	75.6	75.4	74.9	74.7*
Mean	69.1	69.3	69.4	69.1	68.4

* Significant differences

Grain specific weight was lower in Untreated plots overall.

Table 5D Effect of glyphosate pre-harvest on grain specific weight

	Glyphosate	
	+	-
1991		
Gleghornie	68.3	68.3
Niddrie Mains	73.3	75.0*
Remote	75.3	72.8
Mean	72.3	72.8

There was no clear trend reflecting use of glyphosate pre-harvest.

Table 6 Effect of treatment on MOG throughput (t/ha); Scottish sites

		MOG			
		1988	**1989**	**1990**	**1991**
		WW	-	-	**WW**
Gleghornie	Insurance N	11.0	-	-	3.86
	" 0.5N	9.7	-	-	4.19
	Threshold N	9.9	-	-	4.42
	" 0.5N	10.9	-	-	4.43
	Untreated	9.9	-	-	3.61
		WW	-	-	**WW**
Niddrie Mains	Insurance N	8.0	-	-	4.25
	" 0.5N	8.1	-	-	3.93
	Threshold N	8.0	-	-	3.82
	" 0.5N	8.2	-	-	5.52*
	Untreated	7.7	-	-	5.83*
		WW	**WB**	**WB**	
Bush	Insurance N	6.0	4.2	5.40	-
	" 0.5N	5.3	4.0	4.74	-
	Threshold N	5.8	4.4	5.70	-
	" 0.5N	5.6	4.0	5.38	-
	Untreated	6.1	5.0*	5.77	-
		SB	-	-	**SB**
Remote	Insurance N	6.7	-	-	2.65
	" 0.5N	7.8	-	-	3.03
	Threshold N	8.7*	-	-	3.28
	" 0.5N	7.2	-	-	2.80
	Untreated	10.9*	-	-	2.85

* Significant

Treatment rarely had a significant effect on MOG yield, apart from occasional untreated plots.

Table 6B Effects of pre-harvest glyphosate

Site	Treatment +/- glyphosate	MOG throughput harvest 1988	1989	1990	1991
Gleghornie	+	9.9	-	-	6.2
	-	11.5*	-	-	6.2
Niddrie Mains	+	7.8	-	-	6.2
	-	8.2	-	-	6.1
Bush	+	5.4	4.1	4.8	-
	-	6.28	4.5*	6.0*	-
Remote	+	7.6	-	-	6.5
	-	7.7	-	-	6.8*

* Significant

At 7/10 sites, MOG throughput decreased where glyphosate was used.