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Botanical and rotational implications of genetically modified herbicide tolerance in winter oilseed rape and sugar beet (BRIGHT Project)

by

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BRIGHT PROJECT

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BRIGHT REPORT

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1. ABSTRACT

The four year BRIGHT project was initiated in autumn 1998 and the research was conducted by NIAB, Broom's Barn, Rothamsted Research, Morley Research Centre and the Scottish Agricultural College (Aberdeen) in a consortium with Agrovista, BASF, Bayer, BBRO, HGCA and Monsanto sponsored by Defra and SEERAD through the Sustainable Arable LINK programme.

The BRIGHT project had the objective of determining the implications of growing HT crops both for agriculture and the environment by simulating different rotational scenarios, at a number of sites. In the BRIGHT project herbicide tolerant (HT) winter oilseed rape (WOSR) and sugar beet were grown in four year arable rotations with cereals and other crops. Cultivars of sugar beet and WOSR genetically modified to be tolerant to glyphosate and glufosinate were compared to conventional cultivars. Additionally, in years 1 and 2 a cultivar of WOSR resistant to the imidazolinone herbicides, bred by conventional breeding techniques, was compared to the other three. The research programme encompassed whole crop rotations, studying weed control in the non-HT crops as well as the HT crops. The programme included rotations that were perceived to be best practice and worst case scenarios (where potential impact of the use of HT cultivars might be expected to be highest). Thus, two included only oilseed rape or only sugar beet and one was based on a sequence of rape and sugar beet. HT crops were mainly grown twice in each rotation and all possible sequences of HT and conventional cultivars were compared.

The herbicide tolerance systems were effective and flexible, achieving similar or greater levels of weed control, compared to conventional practice, depending on site, season and other factors. The performance of the conventional and HT weed control systems rarely approached total weed control. No significant decreases in botanical (species) diversity were observed. Weed seed banks increased in both WOSR and sugar beet rotations between the start and end of the 4 year project, with no differences detected between treatments. At most sites weed control was more effective in the cereal component of the rotation than it was in the oilseed rape or sugar beet.

Seed banks of volunteer oilseed rape seed left in the field after harvest initially declined rapidly but then persisted at moderate levels with little apparent difference between WOSR varieties. The field studies and Petri-dish tests confirmed that the HT cultivars were no more persistent than the conventional cultivar (Apex). However, appreciable numbers of seeds remained in the seed bank at some sites up to 3 years after the harvest of the WOSR crops.

No direct impact of the transgenes themselves or the transgenic crops on crop production and botanical diversity was observed in these experiments. The only differences observed were due to the different herbicide programmes.

Outcrossing between oilseed rape varieties declined with increasing distance between plots and resulted in combined herbicide tolerance in some instances. Levels of outcrossing matched those reported in other studies in the UK.

Herbicide tolerance in WOSR and sugar beet increased options for the control of weeds in these crops. They gave greater flexibility of timing and management. In most rotations they had little effect on weed management in subsequent crops. However when the same HT was used in sugar beet, following HT WOSR, additional herbicides were needed to control volunteer rape.

The use of HT crops reduced the amount of herbicide active ingredient applied to sugar beet. In both crops the costs of glufosinate, and particularly glyphosate were lower than those of conventional broad-leaved weed and graminicide treatments. Other advantages were greater control of weeds closely related to the crops which are more difficult or expensive to control (e.g. weed beet in sugar beet).

Data from BRIGHT will be used to contribute to guidelines on the management of genetically modified herbicide tolerant crops.

The report recommends further studies to refine the management of HT crops in order to achieve environmental targets as well as agronomic objectives.

2. SUMMARY

The BRIGHT project was initiated in Autumn 1998 and the research was conducted by NIAB, Broom's Barn, Rothamsted Research, Morley Research Centre and the Scottish Agricultural College (Aberdeen) in a consortium with Agrovista, BASF, Bayer, BBRO, HGCA and Monsanto, sponsored by Defra and SEERAD through the Sustainable Arable LINK programme.

The BRIGHT Project had the following objective:
To determine the agronomic implications and the environmental impact (especially botanical effects) of herbicide tolerant oilseed rape and sugar beet grown in a range of rotations, so that guidelines for the agronomy of these crops can be produced to enable farmers to fully exploit these crops while minimising their environmental impact.

The principle products were:

1. A report on the methods, results and conclusions of the research project, including recommendations for the management of GMHT crops, and an executive summary containing the main findings, conclusions and recommendations.
2. Guidelines for the appropriate management of GMHT crops in arable rotations.

Table 2.1 BRIGHT Rotations

Year	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5
1	winter rape	sugar beet	winter rape	winter cereal*	winter cereal*
2	cereal	cereal	cereal	winter rape	cereal
3	cereal	cereal	sugar beet	cereal	sugar beet
4	winter rape	sugar beet	cereal	cereal	cereal

* Cereal under-sown with GM rape or conventional beet seed

Dark shaded areas represent crops where HT and conventional types were compared.

The four year project consisted of a series of 5 rotation experiments which included three herbicide tolerant (HT) winter oilseed rape (WOSR) varieties (glyphosate, glufosinate, imidazolinone tolerant) and two GM HT sugar beet varieties (glyphosate, glufosinate tolerant), together with conventional varieties for

comparison. Rotations 1, 2 and 3 (see Table 2.1) included two crops where the herbicide tolerant cultivars could be studied. Three of the rotations (1, 3 and 4) included the different oilseed rape varieties and were designed to investigate the effects of growing herbicide tolerant rape in both normal farm rotations and in worst case scenarios (e.g. high levels of oilseed rape in the seedbank). One of these rotations (3) studied WOSR in year one followed by the different sugar beet varieties in the third year, so that interactions with the previous GM rape varieties could be studied. The other two rotations (2 and 5) contained the different varieties of sugar beet and examined weed control and interactions between the different varieties. In Rotations 1, 2 and 3 the second broad-leaved crop was grown in randomised sub-plots of the original plots so that all possible sequences could be studied.

The main results are summarised as follows:

i. Impact of HT crops:

a. No direct impacts of the HT varieties, or crops (transgenic and non-transgenic) themselves, on the botanical diversity, or the agronomic systems studied in these experiments, were observed. The GM varieties had very similar agronomic characters to the conventional varieties used in the study. However, the non-GM imidazolinone tolerant variety of WOSR had a lower vernalisation requirement than the other varieties and tended to flower and ripen earlier than the other varieties, especially in the trials in England.

b. There were no observed differences in the establishment, vigour and ground cover of the beet and WOSR varieties in this study. Yields were taken to confirm that management of the crops was realistic and that they had reached acceptable standards. The yields of the varieties and treatments were in line with those described in other programmes which have studied these varieties, bearing in mind that for regulatory reasons the sugar beet had to be harvested early.

c. It appeared that all differences in weed populations and diversity were due to the management of the HT crops and varieties and were not directly due to their genetic make up.

ii. Crop Safety:

a. No treatment produced any lasting phytotoxic effects on their respective WOSR types. Conventional and glufosinate treatments occasionally caused some chlorosis, respectively on conventional and glufosinate tolerant sugar beet, which temporarily checked their vigour during early growth. Glyphosate produced no adverse effects on glyphosate tolerant beet.

b. All tested varieties not tolerant to glyphosate were sensitive to glyphosate and all tested varieties not tolerant to glufosinate were sensitive to glufosinate.

iii. Weed control in winter rape and sugar beet

a. No herbicide tolerant or conventional treatment achieved complete weed control although some approached it at some sites. All treatments gave commercially acceptable weed control in most situations.

b. Overall in WOSR, glyphosate tended to be most effective but there were site/years when other treatments were more active. For example, glufosinate treatment was superior in SAC Aberdeen, Rotation 1 and the conventional treatment was most effective at Morley, Rotation 3. Weed control from imazamox in the imidazolinone tolerant rape was the least effective herbicide in more situations than the other treatments.

c. In beet, the differences between treatments were less clear but again glyphosate tended to give higher levels of weed control in more situations. In 50% of the comparisons there were no clear differences between the treatments; all were equally effective.

d. In most WOSR situations one application of glufosinate or glyphosate was used. In sugar beet a mean of 1.3 applications of glyphosate and 1.7 applications of glufosinate were used to give effective weed control. One or two herbicide products were normally used in conventional WOSR and a mean of 2.7 applications (each including several products) were used in sugar beet.

e. In both beet and WOSR the timing of glyphosate and glufosinate application was more flexible than that of the conventional treatments, which, in WOSR, tended to be based around metazachlor, for broad-leaved weed control. They gave better control of larger weeds and thus were applied 2-8 weeks later. Conventional treatments either had optimum application times at pre- or very early post-emergence, or when applied later had a limited spectrum of activity. This differential was much less acute for grass weed control as conventional treatment with specific graminicides can be applied over a wider range of growth stages in both crops.

f. Glufosinate was less effective on older weeds, particularly grass weeds, than glyphosate, and this has implications for timing of these herbicides. Poor control of *Viola arvensis* by glufosinate was recorded on several sites.

g. Herbicide treatments of WOSR rarely affected weed populations in subsequent cereal crops. This only occurred when the herbicide treatments in the oilseed rape gave large differences in weed control (or failure to control). This was particularly the case with *Alopecurus myosuroides* control in WOSR at NIAB in Rotation 1, where reduced control was apparent in subsequent cereal crops.

h. In WOSR, there was no indication from the analysis of the weed species numbers in spring of year 4 that any particular treatment consistently produced a lower number of species, so that there is no indication that any one treatment reduced botanical diversity more than any other. The weed species which survived a treatment seemed to be dependant on local conditions, the timing of the herbicide application and thus weed escape and survival. In sugar beet, the numbers of surviving weeds in all treatments were very low so that no statistical analyses of effects on botanical diversity were conducted.

i. Weed seedbanks generally increased in the rotations that included oilseed rape and there were a few significant differences due to the earlier treatments. These tended to be linked to marked differences in weed biomass in the relevant years. The high variability between seedbank samples severely reduced the sensitivity of this test masking some potential differences. This increase in the seedbank was in spite of generally high levels of weed control in the cereal crops (NB. poor weed control in barley at SAC in Year 3). The increases detected were much greater than could be attributable to the presence of rape seeds in the seedbank at the end of the rotation, which were not present at the start. In sugar beet, weed seedbanks at Broom's Barn increased as a result of inadequate control of *Chenopodium album.* In Rotation 3, where both WOSR and sugar beet were grown, the seedbank increases due to growing oilseed rape were not offset by cultivating sugar beet in year 3. There were no clear differences between treatments.

iv. Gene Flow

Outcrossing occurred between plots of WOSR at frequencies that matched those from other studies (Eastham & Sweet 2002). Levels decreased exponentially with distance from pollen source. The varietal association Synergy (included as an extra conventional cultivar at NIAB) was pollinated at a higher frequency than other varieties due its low male fertility. Outcrossing between different HT varieties produced seeds with combinations of herbicide tolerance.

Reproductive shoots (bolters) were removed from all beet before they flowered in order to minimise pollen production in the beet experiments. This was a requirement of the Release Consent from DEFRA.

v. Rotational implications

a. In only a few situations was there an influence of herbicides applied to the first rape and sugar beet crops in a rotation, on the weeds and weed control in the second rape/beet crops three years later (Year 4). This suggested that there is often little cumulative effect of the same or different herbicides on weed control. However, this conclusion may have been influenced by the fact that all sites used ploughing as the main method of cultivation. Minimum tillage or non-inversion cultivations could have caused a different effect, but were not tested in BRIGHT. A greater frequency of detectable carry over effects was noted in Rotation 3, where the second treatment year was in Year 3, but the main effects recorded were still those applied in Year 3. These carry-over effects were primarily linked to very poor weed control in the first year treatments (see iii g above).

b. HT oilseed rape volunteers were controlled in oilseed rape and beet possessing a different herbicide tolerance. Where HT rape volunteers appeared in sugar beet with the same HT, then additional herbicides tank mixed with glufosinate and glyphosate were used to control them.

c. Both glufosinate and glyphosate gave good control of non-HT volunteer and weed beet in respective HT beet crops.

d. In cereal crops, the commonly used weed control programmes gave good control of HT oilseed rape including volunteers with more than one HT trait (as a result of gene flow). Overall weed control in the cereals was generally higher than that recorded in the WOSR and sugar beet.

vi. Volunteer rape

a. Over 3500 rape seeds/m^2 were lost at harvest and remained on the soil surface. Seed losses differed slightly between varieties and were not clearly related to yield.

b. The studies showed that GM oilseed rape has similar seed survival characteristics in soil to conventional oilseed rape. Management of the shed seed, seedbank and volunteers post harvest and in intervening crops reduced numbers of volunteers. However, considerable numbers of seeds survived over the 4 year crop rotation (mean 1000 seeds/m^2), supplying a potential source of volunteers to grow and provide admixture in subsequent rape crops.

c. The recommended procedures for reducing the volunteer rape seedbank: delaying post-harvest cultivation until after rainfall, destruction of germinated seedlings through cultivation or herbicide treatment, destroying volunteers in cereal stubble, and control of rape volunteers in cereal crops all helped to minimise numbers of WOSR volunteers.

vii. Costs of weed control

a. A full cost benefit analysis was not possible in BRIGHT, as crop yields do not fully reflect the likely yields of commercial HT cultivars and the sugar beet was harvested atypically early. Provisional costs of weed control were estimated on the basis of herbicide costs and the anticipated technology fee for the glyphosate tolerant cultivars.

b. Mean costs of conventional weed control in WOSR was £60/ha, based on one or two products/crop. Overall, glyphosate was applied only once/crop and glufosinate 1.1 times. This gave costs of £18/ha for glyphosate and £40/ha for glufosinate, but the Monsanto technology fee anticipated to be £20-30/ha needs to be added to the herbicide cost of glyphosate treatment. Thus, both HT treatments were appreciably cheaper than the conventional. This assumed that the HT seed was no more expensive than conventional.

c. The cost of conventional weed control in sugar beet, arising from a mean of 2.7 applications of up to eight herbicides was £84/ha. In contrast the cost of glyphosate treatment (1.3 applications/crop) was £21/ha and was £63/ha for 1.7 applications of glufosinate. Again the cost of the glyphosate technology fee needed to be added to the cost of glyphosate. These calculations indicated that there was an appreciable cost saving of £20-30/ha arising from the planting of both HT sugar beet cultivars.

viii. Discussion and conclusions

a. The herbicide tolerance systems were equally, or more, effective than conventional treatments for weed control. They did not apparently decrease the seed bank, or the species diversity in winter oilseed rape.

Timing of glyphosate and glufosinate application appeared to be much more flexible than that of the conventional treatments for both WOSR and sugar beet. They gave better control of larger weeds and thus could be applied later. Conventional treatments, especially those for broad-leaved weed control, either had optimum application times at pre- or very early post-emergence or had a limited spectrum of activity. This differential was much less acute for grass weed control. The flexibility of conventional treatments for grass weeds would have been much more restricted if they had already acquired resistance to the standard conventional herbicides.

b. Glufosinate was less effective on older weeds, particularly grass weeds, than glyphosate. Therefore it needed to be applied earlier than glyphosate. Both glufosinate and glyphosate have no soil acting residual activity, so that later emerging weeds were not affected. Where these were able to compete with the crop, then a second treatment was needed, reducing the cost benefit. This problem was less acute for glyphosate as activity was not so affected by weed size.

c. Both glufosinate and glyphosate are foliar acting. Consequently, if applications are delayed too long it is possible that crop leaves will screen the weeds, so that they are shielded from the sprays, giving poorer control. This was not explicitly studied in BRIGHT but impacted on decisions as to when to apply the herbicides.

d. Despite the flexibility of glufosinate and glyphosate, both have optimum application windows to achieve good control and without having to be applied twice. The start of the window depends on the end of weed emergence while the end depends on crop ground-cover, which in turn depends on crop vigour driven by crop emergence date and weather. The end of the application window may also be constrained by concern that the weeds will cause irretrievable yield loss. This was not specifically addressed in BRIGHT but was part of the decision making process when deciding on timing of treatments.

e. The research demonstrated some weaknesses in the spectrum of weeds controlled by the HT systems, such as grass weeds and *Viola arvensis* control by glufosinate, so that it could be anticipated that close rotational growing of glufosinate tolerant rape might result in an accumulation of these weeds. This could be overcome by using appropriate tank mixes and greater control of these weeds in other parts of the rotation.

f. Little advantage was seen in following one HT rape crop with a rape crop with a different sensitivity in order to control weeds. Because of the potential of creating volunteers tolerant to more than one herbicide, which could make their control problematic in subsequent years, it would seem appropriate to stay with the same herbicide tolerance in any one rotation. Although, this could encourage the selection of resistant weeds and a build up of HT volunteers, if rape is only grown once in four years and other weed management measures are considered, this should not create problems.

g. The data from BRIGHT enable conclusions to be drawn as to which HT system to use in WOSR. Glyphosate is extensively used for control of rape volunteers in stubbles, set aside and other parts of the rotation and for desiccation of rape crops. By contrast glufosinate is not used widely in other arable crops, but its main use is in desiccation of potatoes and oilseed rape. Thus if glufosinate tolerant rape is grown, glyphosate would still be available for the desiccation of crops and the control of the volunteer rape in stubbles. Tank mixes of other herbicides with glyphosate could be used to control glyphosate tolerant volunteers but this may not be very practical and will add costs and complexity to autumn operations at a busy time of year.

h. In sugar beet, the experiments showed that there was no need to apply pre-emergence herbicides to HT crops and weeds could be controlled at much more advanced growth stages, especially by glyphosate. However, there was also a need to protect young beet seedlings from weed competition in order to achieve rapid crop establishment so that two applications of herbicide were sometimes needed.

i. A major benefit in beet was the ability to control weed beet with a low cost chemical method. Weed beet now infests 70% of the beet area in the UK and is spreading. The main control methods are inter-row hoeing and intra-row hand rogueing, both of which are time consuming and expensive.

j. Since the beet experiments had to be harvested early (September) the full effect of the herbicides on the control of late emerging and late season weeds was not evaluated. In some instances additional treatments may have been needed if beet crops were to be harvested in November/December. In addition greater levels of weed seed return may have occurred.

k. Sugar beet has poor tolerance of weed competition and thus high levels of weed control are much more important in beet than in rape. In rotations containing both rape and beet it thus will be more effective to grow crops with different herbicide tolerances in order to facilitate volunteer rape control. The preferred option would be to utilise glyphosate tolerance in sugar beet.

l. In cereal crops, the commonly used weed control programmes gave good control of HT oilseed rape and beet volunteers, so it may be possible to reduce levels of weed control in cereal crops in the rotation especially if good control of problem weeds is occurring in the HT crops. However, in the BRIGHT cereal plots there was sometimes an appreciable late spring emergence of rape volunteers. In order to ensure that there is no seeding by HT rape volunteers in the cereals and hence carry over into subsequent rape crops, this late cohort was treated with an extra herbicide treatment. This greater use of herbicides such as the sulfonyl ureas (e.g. metsulfuron-methyl) has the potential to reduce populations of other weeds and hence impact on biodiversity in these cereal crops.

ix. Recommendations.

Recommendations for use of HT technology arising from BRIGHT

a. One application of glyphosate will give commercially acceptable levels of weed control in WOSR in most circumstances. Two treatments may be needed for glufosinate.

b. Two applications of both glyphosate and glufosinate are more likely to be needed in sugar beet, especially when the crop is harvested at a ‘normal’ time.

c. Having decided on a particular HT cultivar of WOSR, do not change to a different HT one in subsequent seasons, as this will increase the risk of gene stacking and subsequent problems over volunteer management. The same constraint does not apply to beet provided there is complete control of weed beet and removal of bolters.

d. The results from BRIGHT suggest that if successive crops of HT WOSR and HT beet are to be grown, the use of a different HT cultivar, preferably glufosinate tolerant rape and glyphosate tolerant beet would be advisable. The latter crop is less competitive and therefore would benefit from the higher reliability of glyphosate.

e. In WOSR, it is essential to maximise seed losses post harvest, by using appropriate cultivation options to minimise the size of the subsequent seedbank. A low proportion of the shed seeds will be present after 3 years, and probably longer. This has implications for the cultivar choice in subsequent rape crops. When considering the impact of cultivation of HT beet or WOSR on botanical diversity in arable fields, it is also critical to review the management and impact of cereals grown in rotation with them. It was apparent from this study (and in others) that current weed management methods in cereals often depleted weed numbers more than the treatments in WOSR and beet.

x. Research Recommendations

a. The introduction of GM HT WOSR can create new management issues in subsequent non-HT rape crops or other crops with the same herbicide tolerance. It is proposed that longer term studies of WOSR seedbank decline are conducted using the BRIGHT sites which have already been observed for 4 years, in order to supply more comprehensive information on seedbank decline rates of different HT varieties.

b. The FSE studies showed that glyphosate reduced weed biomass in beet crops. However other studies of HT beet (e.g. in Denmark by Strandberg *et al.,*2002) have contradicted this result and BRIGHT has shown no consistent differences. The increased flexibility of management of HT beet can be used to achieve biodiversity objectives, as has been demonstrated by the studies of Pidgeon *et al* (2001) with HT beet at Broom's Barn, and there is also the possibility that use of HT crops could reduce herbicide usage in cereals offsetting impacts of HT beet. It is therefore proposed that further studies are conducted to determine appropriate management strategies for HT beet and crops in rotation with them that will enhance their environmental profile.

c. In these BRIGHT studies the winter cereals often had a greater impact on the surviving weed numbers than the beet or WOSR, irrespective of whether the weed control was conventional or herbicide tolerant. Thus, other aspects of crop rotational management, apart from weed control, can have as great an impact on botanical diversity in arable systems. If biodiversity impact is to be a major factor in decision making on weed control in arable cropping systems, there is a need to look at the subject holistically across crop rotations and address the potential impacts of all crops, not just those potentially including HT systems. We therefore recommend that studies are carried out to assess the impact on biodiversity of all arable cropping systems and to develop methods to achieve the desired end results.

xi. Guidelines

The use of the information from the BRIGHT project to prepare guidelines on the management of HT crops was part of the original proposal and progress has been made on devising a system to achieve this. The actual preparation and dissemination of the guidelines was without the BRIGHT project. The consortium recommends that the results and conclusions arising from BRIGHT are used, along with other existing data, and the protocols already proposed by SCIMAC, to develop management guidelines for the commercialisation of herbicide tolerant crops in the UK. These guidelines should be prepared prior to planting, but after there is legislative agreement that such HT crops could be sown commercially by UK farmers.

3. INTRODUCTION

Herbicide tolerant crops (maize, oilseed rape, fodder beet, sugar beet) are being developed for UK agriculture and are in the process of being evaluated for commercial planting. These crops are tolerant to broad spectrum herbicides such as glufosinate, imidazolinone herbicides (e.g. imazamox) and glyphosate, which have activity against a very wide range of plant species, both crop and weed. The glufosinate and glyphosate tolerant systems have been introduced into the crops by genetic modification while other systems (e.g. imidazolinone) have been produced by mutation breeding. Some of these herbicide tolerant crops are being widely grown in the USA and Canada. (James, 2003).

These systems permit the use of broad spectrum herbicides at the post- crop emergence phase and thus have the potential to allow greater targeting and control of weeds at this phase. It is important that the agronomy of these crops is understood so that information can be supplied to farmers on how best to manage and exploit these varieties and avoid problems such as volunteer build up, multiple herbicide tolerance, contamination of other crops and reductions in botanical diversity. There are concerns that the use of broad spectrum herbicides may result in much higher levels of weed control and reductions in weed abundance and diversity, which can lead to reductions in the overall biodiversity of arable ecosystems (World Wildlife Fund, 1995; Friends of the Earth, 1998; Gene Watch, 1998; English Nature, 1998; Fromwald & Strauss, 1998; Hill, 1999). The Farm Scale Evaluations (FSE) (Heard *et al* 2003) have already indicated that weed control in glyphosate tolerant beet and glufosinate tolerant spring rape can be higher than in their conventional equivalents, but the Farm Scale studies on winter rape are yet to be published. Other published data suggests that glufosinate applications in winter rape can be as effective as the more active conventional treatments (Read & Ball, 1999). Further data on the impact of HT and conventional treatments are needed, especially over a rotation, as the focus of the FSE trials was on weed control in a single season, and their results cannot be seen in the full context of rotational weed management.

Changes in visible weed populations may result in longer term effects on the soil weed seedbank. The diversity of plant species appearing in crops each year is largely dependent on existing seedbank populations and the management of the crop. In order to determine the effect of one or more herbicide tolerant crops in a rotation, weeds need to be recorded at several stages of crop development and estimates made of seed production. In addition the impact of the different rotational systems on soil seedbank reserves of weeds needs to be determined in order to measure or estimate trends in species or population changes.

It is also important to study the range of interactions that can occur between different HT crops and conventional varieties. This needs to be done in a number of crop rotations simulating anticipated standard practice and practices that would not necessarily be recommended; i.e. best and worst case scenarios. Volunteers are anticipated to be a problem and rotations should be studied where there are likely to be high numbers of volunteers so that their control can be investigated.

3.1 THE BRIGHT PROJECT

The BRIGHT project was established in 1998/9 with the objective of determining the implications of growing HT crops both for agriculture and the environment by simulating different rotational scenarios at a number of sites. In the BRIGHT project herbicide tolerant (HT) oilseed rape and sugar beet have been grown in arable rotations with cereals and other crops. Management studies therefore encompassed whole crop rotations studying the interactions between the crops at all stages of the rotation and the management of the non-HT crops in the rotation as well as the HT crops.

The BRIGHT project started in September 1998 with Pre-LINK funding from DEFRA (MAFF) allowing WOSR to be established that autumn. In spring 1999 a three-year Sustainable Arable LINK programme was agreed with all the sponsors and partners. Only three years funding was initially forthcoming from the industrial partners because they wanted to review the programme at three years in relation to the commercialisation of GMHT crops and other external developments. They also wanted to be sure that the project was addressing the correct issues in relation to the regulatory requirements for the commercialisation of GM crops. In 2001 the EU issued directive 2001/18 EU requiring that the biodiversity implications of growing GM crops be assessed, including the impact of the agronomic practices associated with a GM crop.

BRIGHT had anticipated these regulatory changes by commencing a study of the agronomic and agro-environmental implications of cropping systems containing GM herbicide tolerant crops. It was also a very useful complement to the UK Farm Scale Evaluations (Firbank *et al*., 2003), which were essentially looking at seasonal or short term impacts of GM crops on biodiversity, and to studies in other European countries on the biodiversity implications of GM cropping. In 2001 the industrial sponsors reaffirmed support for the project and a successful submission was made to SA-LINK to extend the project for a fourth year. Field studies were completed in January 2003.

Project objective

To determine the agronomic implications and the environmental impact (especially botanical effects) of herbicide tolerant oilseed rape and sugar beet grown in a range of rotations, so that guidelines for the agronomy of these crops can be produced to enable farmers to fully exploit these crops while minimising their environmental impact.

Scientific objectives

1. Determine the effect of different HT systems on weed species and number in the HT crop.
2. Determine the effect of HT systems on weed species and number in subsequent rotational crops.

3. Determine the longer term implications for arable plant diversity by studying the composition of seedbank populations at the beginning and end of the crop rotations.
4. Determine the principal factors involved in the evolution of HT and multiple HT volunteers.
5. Develop strategies for preventing build up and the control of HT volunteers in different crops.
6. Determine the agronomic benefits of growing HT crops.
7. Identify the most appropriate management systems for HT crops.
8. Identify snags and problems that can arise and ways to avoid or recover from them.
9. Develop strategies for the appropriate management of HT crops that optimise environmental and agronomic impact.
10 Provide information of value for evaluating the risks associated with the release of these crops.
11. Provide information which will contribute to developing systems of post marketing monitoring and risk management of GMHT crops.

4. MATERIALS AND METHODS

4.1 Experimental Design and Site Details

Site Details

Descriptions of individual site soil types and cropping histories are detailed in Appendix 10.3.1.

Plate 4.1.1. Experimental site at Rothamsted Research with winter oilseed rape flowering in the first year of the programme.

Description of crop rotations

The project consisted of a series of large plot experiments to investigate the impact of herbicide tolerant oilseed rape and sugar beet over a series of five, four-year rotations. The herbicide tolerant crops were grown in plots alongside conventional crops and all plots had the same management, except for the herbicide treatments. There were a total of five rotation designs but only a maximum of three were grown at each site (Table 4.1.1).

Deliberate release approvals at the start of the project restricted the areas that could be planted/treated and it was decided that plot size should be as big as possible and replication should be kept to an acceptable minimum, in order to simulate 'normal' field responses. Thus, Rotations 1a, 2, and 3 had only two replications, whilst the smaller plot rotations 4 and 5 had three and six, respectively. The consortium was aware of the limitations of the replication in Rotations 1, 2 and 3 but after statistical consultation concluded that it was acceptable. Even in the smallest trials (rotation 2) there was a total of 18 plots in the critical fourth year (when seeking interactions between the first and second set of treatments) and consequently 8df in the error. Because of the consortium's decision to double-check the statistical validity, Rotations 1 and 3 at Rothamsted and SAC were combined after year 1, whilst they were identical, to become 1a and 1b thus providing two sites with 4 replications of Rotation 1. Problems of achieving adequate replication in field-scale projects with large plots and limited numbers of treatments are discussed by Chapman & McIndoe (2000) in the report of the LINK IFS project. Some of the issues were similar and confirm that the consortium was right to amalgamate the two rotation 1/3 experiments at Rothamsted and SAC, to increase replication. Plot sizes for the main studies with winter oilseed rape (WOSR) (Rotations 1 & 3) initially exceeded 0.2ha but when the second set of treatments was imposed (see below) these were reduced to c. 0.05ha. For Rotation 2 which had sugar beet only, plots were smaller, initially 0.3-0.6 ha reducing to 0.08-0.23 ha in Year 4. Plots were smaller for Rotation 4 & 5. Full details are given in Appendix 10.3.1.

Table 4.1.1 Four year rotation design and participating sites

Year	Rotation 1a/1b[2]	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Sites	NIAB/Roth/SAC	BB/Morley	BB/MOR/NIAB	NIAB/Roth/SAC	BB/Morley
1	Winter oilseed rape	Sugar beet	Winter oilseed rape	Winter cereal[1]	Winter cereal[1]
2	Winter cereal	Winter cereal	Winter cereal	Winter oilseed rape	Winter cereal
3	Winter cereal	Winter cereal	Sugar beet	Winter cereal	Sugar beet
4	Winter oilseed rape	Sugar beet	Cereal	Cereal	Cereal

BB= Broom's Barn, MOR=Morley Research Centre, Roth=Rothamsted Research, NIAB=NIAB, SAC=Scottish Agricultural College, Aberdeen,

[1]The two rotations designated as undersown in year 1 received rape (R.4) or beet (R.5) seeds during late summer which were ploughed under to simulate seeds shed from a previous crop establishing a seedbank of potential volunteers.

[2]NIAB - Rotation 1a only, Rothamsted Research and SAC Aberdeen Rotation 1a and 1b

Herbicide Treatments

Each treatment was replicated at least twice (see above section for details) and the plots in each of the rotations including oilseed rape were sown and treated in the first year as follows:

Glyphosate Tolerant variety, Roundup Ready (RR)	GlufosinateTolerant variety, Liberty Link (LL)	Imazamox Tolerant variety (IMI)	Conventional variety (CONV)

The subsequent broad-leaved crop plots in years 3 or 4 had the same treatments as Year 1 but these were applied to randomised subplots of the first year plots, so that first year treatments were followed by each of the subsequent treatments in oilseed rape (Figure 4.1.2). The randomised layout at each site is described in Appendix 3 in 10.3.1.

The IMI oilseed rape variety was withdrawn from the project after year two and was substituted in later years with an additional conventional variety and treatment (CON*). The herbicide treatment applied to the CON* plots differed from the other conventional treatment and this is commented on in the detailed reports from each site.

The sugar beet varieties were RR, LL and CONV in all their sowing years. However where the RR and LL sugar beet treatments followed oilseed rape RR and LL treatments, other herbicides were included in tank mixes with glyphosate and glufosinate to control tolerant oilseed rape volunteers from the first year. Where sites had been split four ways after Year 1, as occurred in Rotation 3, an additional conventional treatment (CON*) was included which used a different herbicide programme to the other conventional.

Where the experimental layout allowed, herbicide treatments in the years when GMHT crops were being grown had an adjacent untreated area, in order to assess the weed potential in each plot.

Herbicide treatments of non-GM beet and oilseed rape were according to best local practice and the weeds present at the individual sites. All cereal plots at each centre in subsequent years received similar conventional herbicide treatments appropriate to the weed infestation present.

Figure 4.1.2 The sub-division of the year 1 oilseed rape plots in years 3 or 4

RR/RR[x]	RR/LL	RR/CON*	RR/CONV
LL/RR	LL/LL	LL/ CON*	LL/CONV
IMI/RR	IMI/LL	IMI/ CON*	IMI/CONV
CONV/RR	CONV/LL	CONV/CON*	CONV/CONV

x = year 1/subsequent year treatments

4.2 Crop management

Crop management and herbicide applications

Soil types of four of the sites were relatively similar being either sandy/silty clay loams or clay loams. The soil was lighter at Brooms Barn – a sandy loam. Full details are given in Appendix 10.3.1. Normal farm practices for land preparation and crop management were followed for all crops, including fertiliser applications and use of fungicides and insecticides. Most sites were ploughed after the harvest of the test crops (rape and beet) and most were ploughed after the cereal crops. Details are given in Tables 4.3.4 - 4.3.8.

Sowing dates of the crops endeavoured to reflect normal farming practice but difficulties with accessing seeds for some of the GM cultivars meant that sowing of the WOSR and sugar beet tended to be delayed such that the WOSR was sown in early-mid September and sugar beet at the end of April (Tables 4.3.4 – 4.3.8). Despite this, the establishment of all the GM crops was satisfactory at all sites. Site managers aimed to sow the winter cereals early in October.

Herbicide applications to HT oilseed rape and sugar beet variety plots in all experiments followed the recommended rates and timings given by the agrochemical companies supplying the herbicides. Decisions on herbicide products and timings for conventional crops were made by experienced managers at each site and were selected on the basis of weed infestations present at individual sites. The site managers also made decisions on the agronomy of the cereal crops grown in the years when the GM crops were not planted.

Rotations 1 & 2

Details of herbicide applications made at each site for weed control in WOSR and sugar beet are shown in Tables 4.3.1 - 4.3.3. Herbicide applications made to cereal crops in each rotation are shown in Appendix 10.2 (Section 10.2)..

Rotation 3

In year 1 of Rotation 3 the four different oilseed rape varieties were grown and the treatments followed those used on Rotation 1. In year 3 the three different sugar beet varieties were grown. In order to control HT rape volunteers emerging in sugar beet with the same HT, mixtures of herbicides were used (Table 4.3.2). Glufosinate applied to LL sugar beet in year 3 in plots that had LL winter oilseed rape in year 1, had metamitron plus an adjuvant oil added to the first application of glufosinate and triflusulfuron-methyl to the second application to the LL beet, where necessary.

Where glyphosate was applied to plots which had RR winter oilseed rape in year 1, metamitron and adjuvant oil were added to the first RR beet application of glyphosate, and triflusulfuron-methyl to the second application to the RR beet, where necessary.

On plots where IMI and conventional WOSR were sown in year 1, the conventional treatments for beet in year 3 were based on metamitron +/- phenmedipham (cotyledon stage rape only) and/or lenacil + phenmedipham (cotyledon to two true leaves stage rape). Triflusulfuron-methyl was sometimes used on the plots to assist control of the volunteer rape.

Undersown crops

Rotation 4

Plots in Rotation 4 received 'non-dressed' oilseed rape of LL, RR IMI and CONV varieties. Seed was broadcast at a rate of 45g/m^2 (c.10 000 seeds/m^2) in August 1998 to simulate seeds shed from a previous rape crop. Seeds were spread on plots and ploughed into the soil as soon as possible afterwards. The number of volunteers arising from the artificial seedbank was recorded and characterised and their level in the seedbank recorded in winter 1998/99. Treatments in year 2 followed the same pattern as those used in the previous year (year 1) in Rotation 1.

Rotation 5

Plots in Rotation 5 received weed beet (non-GM) seed broadcast at a rate of 46/m^2 to simulate a weed beet problem. Seeds were spread on plots in late summer/early autumn and ploughed into the soil as soon as possible afterwards. The number of volunteers arising from the artificial seedbank was recorded. At Broom's Barn, the experiment was sited on an area previously infested with weed beet. The soil core assessments provided a measure of the weed beet seed abundance. Additional weed beet seed was sown just

prior to drilling the sugar beet in year 3. On 2.5.2001 seed of a Syngenta annual bolting line was broadcast across plots at a rate of 1.7 seeds/sqm onto plots prior to final seed bed preparation by power harrowing.
In year 3, HT and conventional beet was grown using the herbicide treatments specified in Table 4.3.3. The weeds were assessed as in Rotations 2 and 3 and beet seedlings emerging between the rows were included in the weed assessments.

4.3 Herbicide treatments and agronomic details for each rotation at each centre

The following tables (4.3.1 - 4.3.3) list the herbicide treatments applied when oilseed rape or sugar beet were grown in rotations to compare treatments. Full details of herbicide applications are shown in Appendix 1 (Section 10.1).

Table 4.3.1 Herbicide treatments in oilseed rape crops in Rotations 1a and 1b at NIAB , Rothamsted and SAC in years 1 and 4

Rotation	Site	Year	Treatment	Date of application	Herbicides used
1	NIAB	1	CON	11.11.98	metazachlor + fluazifop
			LL	23.11.98	glufosinate
			RR	23.11.98	glyphosate
			IMI	23.11.98	imazamox
1a/1b	RES	1	CON	28.09.98	metazachlor
			CON	11.11. 98	cycloxydim
			LL	11.11. 98	glufosinate
			RR	11.11. 98	glyphosate
			IMI	9.10.98	imazamox
1a/1b	SAC	1	CON	6.11.98	metazachlor + benazolin + clopyralid
			LL	17.11.98	glufosinate
			RR	19.11.98	glyphosate
			IMI	6.11.98	imazamox
1a	NIAB	4	CON	6.09.01	metazachlor + quinmerac
			CON	25.09.01	cycloxydim
			LL	25.09.01	glufosinate
			LL	6.11.01	glufosinate
			RR	25.09.01	glyphosate
			CON*	25.09.01	cycloxydim
1a/1b	RES	4	CON	28.09.01	metazachlor + quinmerac
			LL	1.11.01	glufosinate
			RR	2.11.01	glyphosate
			CON*	20.10.01	cyanazine
1a/1b	SAC	4	CON	5.09.01	metazachlor + quinmerac
			LL	26.11.01	glufosinate
			RR	26.11.01	glyphosate
			CON*	26.11.01	propyzamide

CON* is an alternative conventional treatment applied to replace the imidazolinone treatment (previously referred to as IMIC).

Table 4.3.2. Herbicide treatments in winter oilseed rape and sugar beet crops in Rotation 3 at NIAB, Broom's Barn and Morley

Rotation	Site	Year	Treatment	Date of application	Herbicides used
3	NIAB	1	CON	15.10.98	metazachlor + fluazifop
			LL	16.10.98	glufosinate
			RR	23.11.98	glyphosate
			IMI (Con)#	15.10.98	metazachlor + fluazifop
3	Brooms Barn	1	CON	2.02.99	benazolin + clopyralid + cycloxydim
			LL	2.02.99	glufosinate
			RR	2.02.99	glyphosate
			IMI (Con)#	2.02.99	benazolin + clopyralid
3	Morley	1	CON	12.09.98	metazachlor (pre-em)
			LL	11.11.98	glufosinate
			RR	11.11.98	glyphosate
			IMI(Con)#	11.11.98	metazachlor + benazolin + clopyralid
3	NIAB	3	CON	8.05.01	metamitron + ethofumesate
				25.05.01	triflusulfuron-methyl + desmedipham + phenmedipham
				7.06.01	triflusulfuron-methyl + desmedipham + phenmedipham
			CON*	17.04.01	chloridazon (pre-em) + same post-emergence treatments as CON
			LL	21.05.01	glufosinate (+metamitron)**
				5.06.01	glufosinate
			RR	31.05.01	glyphosate (+metamitron)**
3	Brooms Barn	3	CON	23.05.01	phenmedipham+lenacil
				12.06.01	desmedipham+ethofume sate+ phenmedipham triflusulfuron +lenacil
			LL	13.06.01	glufosinate (+metamitron)**
			RR	13.06.01	glyphosate (+metamitron)**

** LL and RR plots that followed LL and RR rape in year 1 received a tank mix of metamitron to control herbicide tolerant oilseed rape volunteers

IMI(Con) was sown with imidazolinone tolerant rape but due to approval limitations was treated with conventional herbicides.

Table 4.3.2 ***(continued)*** **Herbicide treatments in winter oilseed rape and sugar beet crops in Rotation 3 at NIAB, Broom's Barn and Morley**

Rotation	Site	Year	Treatment	Date of application	Herbicides used
3	Morley	3	CON	4.05.01	chloridazon (pre-em)
				30.05.01	Phenmedipham+lenacil
				22.06.01	Phenmedipham+lenacil
				9.07.01	phenmedipham+desmedipham + ethofumesate + lenacil
			LL	12.06.01	glufosinate (+metamitron)**
			LL	16.07.01	glufosinate (+triflusulfuron)**
			RR	12.06.01	glyphosate(+ metamitron)**
			RR	16.07.01	glyphosate (+triflusulfuron)**

** LL and RR plots that followed LL and RR rape in year 1 received a tank mix of metamitron and then one with triflusulfuron to control herbicide tolerant oilseed rape volunteers.

Table 4.3.3. Herbicide treatments in sugar beet crops in Rotations 2 & 5 at Broom's Barn and Morley.

Rotation	Site	Year	Treatment	Date of application	Herbicides used
2	Broom's Barn	1	CON	19.05.99	metamitron+phenmedipham
				14.06.99	desmedipham+ethofumesate+ phenmedipham
				14.06.99	metamitron+clopyralid
			LL	14.06.99	glufosinate
			LL	6.08.99	glufosinate
			RR	14.06.99	glyphosate
		4	CON	30.03.02	chloridazon
				16.04.02	phenmedipham + lenacil
				24.04.02	phenmedipham + lenacil
				19.06.02	ethofumesate + phenmedipham + clopyralid
			LL	8.06.02	glufosinate
			LL	12.07.02	glufosinate
			RR	8.06.02	glyphosate
2	Morley	4	CON	3.04.02	chloridazon
				10.05.02	phenmedipham + metamitron
				6.06.02	phenmedipham + lenacil
			LL	6.06.02	glufosinate
			RR	6.06.02	glyphosate
5	Broom's Barn	3	CON	23.05.01	ethofumesate: phenmedipham + metamitron
				12.06.01	ethofumesate: phenmedipham + metamitron
			LL	13.06.01	glufosinate
			RR	13.06.01	glyphosate

Herbicide treatments at Morley in Rotn 5 were similar to those at Broom's Barn and are described in Appendix 10.1.

Herbicide treatments of cereal crops

Cereal crops were grown in rotations which differed from centre to centre and received different herbicide treatments at each centre in each year. These are described in Appendix 2 (Section 10.2). Each site used treatments appropriate to their local conditions. These herbicide treatments were applied uniformly across each site in each season and rotation so that there were no different treatments.

Details of sowing cultivation and harvesting

The following tables present details of the cultivation and dates of sowing and harvest in each of the four years.

Table 4.3.4 Rotation 1a and 1b years 1-4, dates of cultivation, drilling and harvest at NIAB*, Rothamsted Research and Scottish Agricultural College Aberdeen****

Site/Year	Crop	Primary cultivation/date	Crop drilling date	Crop harvest date
NIAB year1	WOSR	Subsoil:1.09.98 Ploughed: 2.09.98	16-17.09.98	Swath: 9.07.98 Harvest:13.07.98
NIAB year 2	W. wheat	Subsoil:26.08.99 Ploughed: 31.08.99	07.10.99	28.07.00
NIAB year 3	W. wheat	Ploughed: 5.07.00	11.10.01	18.08.01
NIAB year 4	WOSR	Min till: 26.08.01	31.08.01-3.09.01	Direct cut: 16-19.07.02
Rothamsted Research year 1	WOSR	Ploughed: 1-2.09.98	4.09.98	Desiccated: 14.07.99 Harvest: 21.07.99
Rothamsted Research year 2	W. wheat	Ploughed: 24.07.99 + 25.08.99	9.10.99	16.08.00
Rothamsted Research year 3	W. wheat	Ploughed: 29-30.08.00	30.09.00-01.10.00	14.08.01
Rothamsted Research year 4	WOSR	Ploughed: 24-25.08.01	05.09.01	Desiccated: 16.07.02 Harvest: 24.07.02
SAC Aberdeen year 1	WOSR	Ploughed: 11-14.09.98	15.09.98	Swath: 30.7.99 Harvest 8-9.8.99
SAC Aberdeen year 2	W. barley	Ploughed: 10.08.99	18.09.99	07.08.00
SAC Aberdeen year 3	W. barley	Ploughed: - Sept 00	7.10.00	24.08.01
SAC Aberdeen year 4	WOSR	Ploughed: 25-28.08.01	30.09.01	Swath: 07.08.02 Harvest 18-19.08.02

*NIAB: Rotation 1a **Rothamsted Research and SAC Aberdeen: Rotation 1a and Rotation1b

Table 4.3.5. Rotation 3 years 1-4, dates of cultivation, drilling and harvest at Brooms Barn, NIAB and Morley Research Centre

Site/Year	Crop	Primary cultivation/date	Crop drilling date	Crop harvest date
NIAB year 1	WOSR	Ploughed: 20.08.98	20-27.08.98	Swath: 1.07.99 Harvest: 9.07.99
NIAB year 2	W. wheat	Ploughed: 22.08.99	11.10.99	28.07.99
NIAB year 3	Sugar beet	Ploughed: 19.12.00	12.04.01	24.09.01
NIAB year 4	W. wheat	Ploughed: 03.10.01	11.10.01	19.08.02
Brooms Barn year 1	WOSR	Ploughed: 16.09.98	21-22.09.98	23-24.07.99
Brooms Barn year 2	W. barley	Ploughed: 28.07.99	18.09.99	26.07.00
Brooms Barn year 3	Sugar beet	Ploughed: 03.10.01	09.05.01	10.09.01
Brooms Barn year 4	W. barley	Ploughed/Disc: 13.09.01	28.09.01	26.07.02
Morley Res. year 1	WOSR	Ploughed: 3.09.98	11.09.98	31.07.99
Morley Res. year 2	W. wheat	Ploughed: 20.08.99	17.03.00*	25.08.00
Morley Res. year 3	Sugar beet	Ploughed: 3.12.00	3.05.01	17.09.01
Morley Res. year 4	W. wheat	Ploughed: 3.09.98	11.10.01	06.08.02

* autumn sown wheat crop failed and site resown in spring.

Table 4.3.6 Rotation 4, Years 1-4, dates of cultivation, drilling and harvest at NIAB, Rothamsted Research and Scottish Agricultural College Aberdeen

Site	Crop	Primary cultivation/date	Crop drillling date	Crop harvest date
NIAB year 1*	W. wheat	Ploughed: 4.09.98	20.10.98	17.06.99
NIAB year 2	WOSR	Ploughed: 20.08.99	9.09.99	Swath: 7.07.00 Harvest: 18.07.00
NIAB year 3	W. wheat	Ploughed: 27.09.00	17.01.01	18.08.01
NIAB year 4	W. wheat	Ploughed: 12.09.01	17.10.01	17.08.02
Rothamsted Research year 1*	W. wheat	Ploughed: 02.09.98	16.09.98	31.07.99-1.08.98
Rothamsted Research year 2	WOSR	Ploughed: 26-27.08.99	10.09.99	Desiccation: 12.07.00 Harvest: 25.07.99
Rothamsted Research year 3	W. wheat	Ploughed: 29-30.08.00	30.09.00	14.08.01
Rothamsted Research year 4	W. wheat	Ploughed: 24-25.08.01	13.09.01	16.08.02
SAC Aberdeen year 1*	W. barley	Ploughed: 14.09.98	October 98	5.08.99
SAC Aberdeen year 2	WOSR	Ploughed: 10.08.99 Power harrow: 03.09.99	06.09.99 for Conv, RR and LL varieties 10.09.99 for IMI	Swath: 17.08.00 - 08.09.00 Harvest: 08.09.00 - 17.09.00
SAC Aberdeen year 3	W. barley	Ploughed: Oct. 00	October 00	24.08.01
SAC Aberdeen year 4	W. barley	Ploughed: Aug. 01	October 01	11.08.02

*In year 1 rape seeds were broadcast pre-sowing of the winter wheat crop at a rate of approximately 10 000 seeds/m^2 (varieties CONV, LL, RR, IMI)

Table 4.3.7 Rotation 2 years 1-4, dates of cultivation, drilling and harvest at Broom's Barn and Morley

Site/Year	Crop	Primary cultivation/date	Crop drillling date	Crop harvest date
Broom's Barn year 1	Sugar beet	Subsoil: 04.09.98 Ploughed: 16.09.98	30.04.99	03.09.99
Broom's Barn year 2	W. barley	Ploughed: 14.09.99	18.09.99	26.07.00
Broom's Barn year 3	W. barley	Ploughed: 03.10.00	4.10.00	28.07.01
Broom' s Barn year 4	Sugar beet	Ploughed: 18.12.01	27.03.02	30.08.02
Morley year 1	Sugar beet	Ploughed 1.11.98	29.04 99	2.09.99
Morley year 2.	W. wheat	Plough/press 16.9.99	16.9.99	25.8.00
Morley year 3	W. wheat	Plough/Press 24.10 00	24.10.00	31.08.01
Morley year 4	Sugar beet	Ploughed: 10.12.01	3.04.02	2.09.02

Table 4.3.8. Rotation 5 years 3-4, dates of cultivation, drilling and harvest at Broom's Barn and Morley

Site/Year	Crop	Primary cultivation/date	Crop drillling date	Crop harvest date
Broom's Barn year 3	Sugar beet	Ploughed:04.10.00	04.05.01	10.09.01
Broom's Barn year 4	W. barley	Ploughed/Disc:13.09.01	27.09.01	27.07.02
Morley year 3	Sugar beet	Ploughed 14.09.00	03.05.01	21-28.09.01
Morley year 4	W. wheat	Ploughed/pressed 09.10.01	9/10/01	21.08.02

4.4 Weed and crop assessment methods

Introduction

Weed species and plant numbers were assessed in each treatment in each season. Control of tolerant and non-tolerant oilseed rape volunteers was noted in crops following oilseed rape. Sugar beet volunteers were assessed in Rotation 5. Assessments were conducted to determine the following:

- weed plant populations prior to herbicide treatment.
- weed plant populations at various times after herbicide treatment
- weed biomass prior to harvest (at time of maximum weed growth)
- crop yield.
- weed seedbank levels at the beginning of the project prior to any herbicide treatments and at the end of the project after the final herbicide treatment and weed assessments. (i.e. the autumn of Year 1 and the spring/summer/autumn of Year 4).
- Volunteer WOSR seedbanks each winter following an initial WOSR crop.

Full details of the dates and methods of assessment are given in the Appendices (10.3.4). All assessments were based on agreed 'Standard Operating Procedures (SOPs) written by the the research team. Therse were collated and retained by the project co-ordinator.

Weed counts were carried out pre- and post-herbicide application. The timings of these counts varied between crop species. Pre-herbicide application counts were normally either carried out in autumn (for winter oilseed rape and winter cereals) or spring/summer (for sugar beet). These timings gave an idea of the background weed population structure.

Post-herbicide application counts were either carried out in the spring (for oilseed rape and winter cereals) or summer (for sugar beet). This timing gave an indication of weed species that were not killed by the herbicides and in the case of autumn sown crops, which species were spring germinating and therefore would not be affected by an autumn herbicide application. Weed biomass was measured on plots in late summer, at a time when the weeds had reached their maximum size (June/July for oilseed rape and cereals, August for sugar beet. This measurement was used to indicate weed survival and to provide some information on seed production on the basis that weed weight gives a reasonable indication of reproductive success (Lutman, 2002).

Pre-herbicide application weed assessments

The timing of these counts depended on the plot treatment, as glyphosate and glufosinate were applied later than the conventional herbicides, and on the crop (oilseed rape/sugar beet/cereal). Counts were carried out immediately prior to treatment, where possible. The size of the random quadrats counted varied between sites due to weed infestation levels. All sites counted a minimum of twelve quadrats per sub-plot. Details of sizes used are given in Appendix 10.3.4

Untreated fixed quadrats

At some sites when the test crops of sugar beet and WOSR were grown, untreated quadrats or areas were used as a comparison with the treated plots. These were counted pre-herbicide. The size of quadrat / assessment area depended on the site, crop and weed levels but was normally $0.5m^2$ or $1m^2$. Where possible the areas were counted again when the later treatments were applied. This gave an indication of any subsequent weed emergence.

Post-herbicide application weed assessment

The same number of quadrats in each sub-plot was counted as in the pre-herbicide assessment. The timing of this count varied with crop and the site. For oilseed rape the count was carried out in early spring, in sugar beet the counts were done in summer, about 6 weeks after the last herbicide application.

The same procedure was used for weed counts in the test crops of rape and sugar beet and in the cereal crops. Particular care was taken in the cereal crops to assess any volunteer rape seedlings. In some cereal crops weed emergence in autumn was very low and consequently counts were delayed until the spring/summer. Full details of dates and quadrat numbers and sizes are in Appendix 10.3.4.

Weed biomass assessment

Each sub-plot was sampled using 2 or 4 quadrats up to $1m^2$ each, during June for rape, July for cereals and August/September for sugar beet. The exact number and size of quadrats sampled depended on the density of the weeds or if the sub-plots were small. Three–sided $1m^2$ quadrats (or 2 three-sided $0.5m^2$) were used which could be slid into the crop at the desired position (the position of the fourth side was estimated). In rape the sample areas were at least 1.5m from any tramlines or pathways.

All the above ground vegetation (except the crop) was collected by cutting it at ground level with shears or knives. The weeds were sorted into species, washed if necessary and then the dry weights of each species were recorded.

Analysis of weed species diversity (Rotation 1)

There are a number of ecological techniques that can be used to explore variation in species diversity. One widely used technique to assess effects on species diversity is simply to count the number of species (S) on each plot and then do a standard ANOVA to determine any treatment effects. However, this analysis could be biased by the weed density; on the basis that the more individuals present the greater the species number is likely to be. One way of resolving this issue is to include weed plant number/plot (log transformed) as a covariate in the analysis of species number(s) (SLogN). In the BRIGHT oilseed rape experiments (Rotation 1) herbicide treatments were applied in autumn year 1 and again in autumn year 4. As the two year's of treatments were factorialised it was possible to explore the impact of different combinations of treatments on species number, provided the assessment of surviving weeds was done after the impact of the second GM crop treatment was apparent. Thus the subsequent conclusions are based on the assessment of total weed numbers and of species number in spring of year 4.

There is one consequence of this type of analysis to detect effects of sequences of treatments. If the species present on one replicate are different from those in another, but the total species number is the same (e.g. 10), the analysis will assume that there is a mean of 10 species on these two plots. In reality there may be more than 10. This cannot be resolved within the constraints of analysis of variance, which is endeavouring to detect statistically sound treatment effects. This means that total species number/treatment may be less than what is actually present on the site. However, it does not negate the validity of the treatment comparisons.

Two other techniques frequently used for assessment of species diversity differences were also investigated; Log series α and Berger-Parker dominance (Magurran, 1988). The latter identifies the importance of the most dominant species whilst the former assesses species number in a slightly different way to SlogN. All three of these techniques were also used in the FSE studies (Heard *et al*., 2003).

Visual assessments

A range of visual assessments were made throughout the growing season in each year in order to monitor crop and weed growth. These included assessments of percentage cover of weeds and crop, percentage control of weed species and assessment of crop damage post-herbicide treatment. The results of these assessments were not analysed and are not presented, but are used to assist with the interpretation of results at each centre. These records are kept on file at each centre and can be inspected on request.

Crop yields

Yields were recorded for both WOSR and sugar beet at all five sites. For WOSR that was not swathed, single or multiple combine cuts of defined length (generally the length of the plots) were harvested and the seed weighed and sampled. Single cuts were used when plots were small (eg Rotn 4) or where the plot was very long, as in the Year 1 rape plots. Areas harvested per plot exceeded $75m^2$ in the main rotations 1 and 3. Sub-samples were taken to estimate moisture content and yields were re-calculated at 9% moisture. Where the WOSR was swathed whole plots were harvested at NIAB and SAC (year 1) and the entire output was weighed. At SAC in year 4 two swathes (4.27m wide) / plot were harvested and weighed. In sugar beet the roots were harvested from at least 2 rows/plot (harvesting full length of plots) using a mobile tare house which washed and weighed the roots and extracted samples which were processed to determine sugar content. Yields were calculated as fresh weight per hectare, sugar content and sugar yield per hectare. The full description of the mobile tare house operation is available from the authors on request.

Additional assessments relating to volunteer rape

Rotation 1

Immediately after the applications of glyphosate and glufosinate to the WOSR in Year 4, quadrats were counted on each sub plot, once the herbicide symptoms were apparent, to assess the number of volunteer rape plants (arising from cultivars planted in year 1) killed by the two herbicides (See Table 4.7.3 for details).

Rotation 3

Prior to the first applications of glyphosate and glufosinate to the beet varieties in Year 3, volunteer oilseed rape plants were counted on each plot treated with these herbicides. A 3m (approx) strip along one edge of each subplot (using the same side on each subplot) was treated only with glufosinate or glyphosate whereas the tank mixtures were applied on the main part of the plots.

Between 10 and 25 days after application of glyphosate and glufosinate, the number of rape plants that survived treatment was counted. Newly emerged rape plants (cotyledon to early true leaves stage plants) were counted separately so that they could be distinguished from plants surviving post-emergence treatment. Doing this allowed both the total numbers of rape volunteers and the number tolerant to either glufosinate or glyphosate to be estimated in each plot.

4.5 Soil core sampling in years 1 and 4 to determine weed seedbank composition

Introduction

As part of the assessments on BRIGHT, soil cores were taken from Rotations 1a and 1b, 2 and 3 in the autumn of Year 1, prior to any treatment of the soil, and again in the same places in the spring/summer/autumn of Year 4. The second sample was taken once all the herbicides had been applied and no further seed return from surviving weeds was possible. The soil was sieved and seeds were extracted and identified so that the weed seedbank could be analysed at these two points in time and therefore pinpoint any changes in seed numbers of individual weed species which may have occurred.

Soil sampling protocol

Each sub-plot was divided into 4 zones and the middle marked. A square 2m x 2m around each mid point was marked and 12 cores were taken at random within that area i.e. a total of 48 cores, 2.5cm diameter and 25-30cm deep from each sub plot. All the soil from each position was bulked, but the four zones within each sub-plot were kept separate. Thus for each sub-plot there were 4 samples each containing 12 cores of soil.

The soil from each bag of 12 cores was weighed and thoroughly mixed and 1 sub sample of 500g was removed for processing. Where necessary, samples were stored frozen at -20^{o}C prior to processing.

Seed extraction from soil samples

This method of seedbank determination involved extraction and identification of seeds. Direct counting of the extracted seeds determined the total seed numbers in the soil. The technique was based on that described by Roberts and Ricketts (1979). Soil samples were processed using a wet sieving technique. A Fritsch Analysette vibratory shaker was set up with a stack of sieves (4mm, 1mm and 0.5mm, 0.25mm) and set to vibrate/sieve for approximately 20-25 mins depending on soil type. The process was completed once the outflow water was clear, signifying that all the soil had been washed though.

The sieve stack was then dismantled and the top sieve checked for any large seeds. The sediment was washed from the other sieves into a large Petri dish by using a water jet and a brush and the washings inspected for seeds. The sediment was checked for seeds by adding 50-100ml of a saturated solution of calcium chloride ($CaCl_2$) which caused the seeds to float. The solution was stirred and inspected for seeds under a large lens.

Seeds were either identified and recorded immediately or stored in sample bottles for later identification. To determine apparent viability, seeds were inspected and gently squeezed between forceps, firm seeds were assumed to be viable (Ball and Miller, 1990).

4.6 Studies of cross pollination between herbicide tolerant and conventional varieties of winter oilseed rape

Experimental Sites

NIAB, Cambridge

Two blocks of three herbicide tolerant and two conventional winter oilseed rape varieties were established in adjacent areas of 92m x 92m in a 10 hectare field in autumn 1998 (Rotation 1a) at NIAB experimental farm, Cambridge, UK.

Rothamsted Research, Harpenden

Four blocks of three herbicide tolerant and a conventional winter oilseed rape variety (24m x 120m) were established in autumn 1998 (Rotation 1a and 1b) at Rothamsted Research experimental farm, Harpenden UK. (Figure 6.8.5 and 6.8.6).

Scottish Agricultural College, Aberdeen

Four blocks of three herbicide tolerant and a conventional winter oilseed rape variety (24m x 120m) were established in autumn 1998 (Rotation 1a and 1b) at Scottish Agricultural College, Aberdeen, UK. (Figure 6.8.7).

Seed sampling and testing procedure

Location of sampling points at NIAB

Three linear transects across each block were sampled at 1.5m, 6.5m, 11.5m, 16.5m, 21.5m, 41.5m, 61.5m and 81.5m from the adjacent oilseed rape variety. Conventional plots, which contained two winter rape varieties in smaller but equal areas, were sampled at more frequent distances; 1.5m, 6.5m, 11.5m, 16.5m, 21.5m, 26.5m, 31.5m, 41.5m, 51.5m, 61.5m, 71.5m, 81.5m, 91.5m.

Location of sampling points at Rothamsted Research

A similar layout of sampling points was used as described above, although in the smaller plots only 5 distances across each transect were sampled (0m, 5m, 10m, 15m, 20m away from the ‘test’ herbicide tolerant variety).

Location of sampling points at SAC

Samples were taken at the same distances described for Rothamsted Research. Seed samples were only taken from the conventional variety plots and were tested for glufosinate and glyphosate tolerance.

Seed harvesting

The main raceme was removed from 20 plants within a $1m^2$ quadrat at each sample point. Racemes were collected in large cloth bags and dried in ambient conditions for approximately 14 days. Seeds were removed from pods by crushing the racemes in cloth bags and hand sieving to remove debris.

Seed testing for herbicide tolerance

NIAB

Seeds were randomly sub-sampled in order to test two replicates of 1000 seeds per sample using a digital automated seed counter. Seed samples of GM herbicide tolerant and conventional winter oilseed rape varieties were grown in seed trays containing a multi-purpose peat based potting compost under glasshouse conditions. A herbicide susceptible control (a conventional non-tolerant winter oilseed rape variety; Falcon or Apex) was grown with each herbicide tolerance test. Trays were arranged on glasshouse benches using a randomised block design. Plants were sprayed at growth stage 1.2 with either glufosinate-ammonium (200g/l) in a 1% solution, glyphosate (360 g/l) in a 0.5% solution or with imazamox (40g/l + wetter) in a 1% solution, applied using a hand sprayer. The numbers of surviving plants were assessed approximately 10-15 days after treatment for glufosinate, and after 15 -25 days for glyphosate and imazamox. Survivors from each replicate of 1000 plants were re-treated with herbicide at growth stage 1.3. Surviving plants were counted after the same intervals as the first treatment.

Rothamsted Research

The herbicide tolerance test at Rothamsted used a similar method as described for NIAB except 100 seeds were tested per replicate and a 1% solution of both herbicides was applied. All plots were sampled and tested for their tolerance to either glufosinate or glyphosate. No imazamox tolerance testing was carried out at Rothamsted.

Scottish Agricultural College

The same method was used as described above for Rothamsted. No imazamox tolerance testing was carried out at SAC.

4.7 The behaviour of seeds of oilseed rape after crop harvest and in subsequent years

Seed losses at harvest

Estimates of the number of seeds remaining in the field after harvest were obtained by counting quadrats in each plot the day after harvest (NIAB, Rothamsted, Scottish Agricultural College (SAC)), or, by collection of seeds in gutters at harvest (Brooms Barn, Morley). Quadrat and gutter number and size varied according to each site and each year (Table 4.7.1). Numbers of quadrats counted in Year 4 tended to be lower than in the previous years, as the data were intended simply to confirm earlier trends and were not to form the basis of calculations of seed decline in subsequent years.

Table 4.7.1 The number and size of quadrats or gutters used to count oilseed rape seeds for each site and year

Site	Year	Rotation	Seed loss collection method
Rothamsted	1	1	5 quadrats (10x10cm) per plot
	2	4	6 quadrats (10x10cm) per plot
	4	1	3 quadrats (10x10cm) per plot
NIAB	1	1 and 3	10 quadrats (15x15cm) per plot
	2	4	5 quadrats (10x10cm) per plot
	4	1 and 3	3 quadrats (20x20cm) per plot
SAC	1	1	15 quadrats (10x10cm) per plot. (10 quadrats under swathe, 5 outside swathe)
	2	4	15 quadrats (10x10cm) per plot (10 quadrats under swathe, 5 outside swathe)
	4	1	3 quadrats (20x20cm) per plot (2 quadrats under swathe, 1 outside swathe)
Brooms Barn	1	3	4 gutters ($0.22m^2$) per plot
Morley	1	3	3 gutters ($0.22m^2$) per plot

Post-harvest seed counts and seed germination

Rape seeds, or seedlings, post-harvest were counted on Rotation 1a/b (Year 1 and 4) and Rotation 4 (Year 2) at SAC and Rothamsted only. In year 1 and 2 SAC counted two quadrats per plot from under the swathe 19 days post harvest. At Rothamsted in Year 1 all quadrats were re-counted twice, at 10 and 22 days post harvest, whilst in Year 2 all quadrats were counted 3 times at 8, 16 and 22 days after harvest. In Year 4 all quadrats were re-counted 13 days after harvest. The quadrats were the same size as those used to count seeds lost at harvest (Table 4.7.1)

Estimation of the numbers of oilseed rape seeds in the seedbank

Each winter after an oilseed rape crop soil cores were taken at all sites to assess the decline in the rape seedbank (Table 4.7.2). At all sites the cores taken were 2.5cm diameter by 25-30cm depth, to ensure that the soil was sampled down to below the plough layer. The number of cores increased after the first winter as there were fewer rape seeds present. Numbers of cores and month of sampling are given in Table 4.7.2. When possible the soil sample was washed out immediately using a 4mm and a 1mm sieve. Otherwise, the sample was frozen and washed out as above at a later date. Whole seeds were then removed from the contents of the 1mm sieve. The seeds were squeezed to test their viability and viable seed numbers were recorded.

Table 4.7.2 Date and number of cores taken to assess rape seed decline in the seedbank.

Site	Rotation	Number of cores per plot	Dates
Rothamsted	1	40	Jan - Feb 2000 (Yr 2)
		80	Jan - Feb 2001 (Yr 3); Jan 2002 (Yr 4)
	4	80	Feb 2001 (Yr 3); Feb 2002 (Yr 4)
NIAB	1	50	Nov 1999 (Yr 2)
		80	Nov 2000 (Yr 3); Nov 2001 (Yr 4)
	3	50	Jan 2000 (Yr 2)
		80	Jan 2001 (Yr 3); Dec 2001 (Yr 4)
	4	80	Mar 2001 (Yr 3); Mar 2002 (Yr 4)
SAC	1	40	Mar 2000 (Yr 2)
		80	April 2001 (Yr 3); Feb 2002 (Yr 4)
	4	40	April 2001 (Yr 3)
		80	Feb 2002 (Yr 4)
Broom's	3	40	Nov 1999 (Yr 2)
Barn		60	Dec 2000 (Yr 3); Jan 2002 (Yr 4)
Morley	3	24	Mar 2000 (Yr 2)
		30	Feb 2001 (Yr 3)
		60	Feb 2002 (Yr 4)

Intrinsic dormancy of the cultivars of oilseed rape used in the BRIGHT project (Rothamsted test).

Seeds were harvested from the four cultivars grown on the BRIGHT trials in July 1999 at Rothamsted Research (RES) and Brooms Barn (BB). After harvest the seeds were stored in seed store until ready to use (20ºC ± 2ºC). In October 1999 two tests were done. In the first, 50 seeds of the four cultivars, replicated 6 times, were placed in Petri-dishes with 7ml of water, in the light in an incubator at 20^{o}C. These were left for a week and germinated seeds were counted. In the second experiment the same numbers of seeds were placed in Petri dishes containing Polyethylene glycol (PE.G. 6000) at a concentrating aimed to generate a water potential of –1.5Mpa (for details see Pekrun *et al.,* 1997). There were again six replicates. These seeds were placed in the dark in an incubator at a constant temperature of 20ºC for 4 weeks. After 4 weeks seeds were examined under a green safe light and any germinated or mouldy seeds were removed. The seeds were then transferred to clean Petri-dishes containing 8ml of clean water and were returned to the dark incubator for a further 2 weeks. The number of germinated seeds was recorded. This experiment was repeated in January 2000. The data on numbers of germinated seeds were transformed using logit transformations, the results of the two tests were amalgamated and means and standard errors calculated.

Estimates of the proportion of the rape seedbank that emerges and produces new plants.

Following the application of glyphosate and glufosinate to the rape grown in year 4 in Rotation 1, volunteers of the other cultivars arising from the crops sown in year 1, showed symptoms of phytotoxicity and eventually died. These dying plants were counted on random quadrats placed on the affected plots (Table 4.7.3). These assessments were done at NIAB, Rothamsted and the Scottish Agricultural College.

Table 4.7.3 Details of dates and assessment methods used to record the number of dying rape plants present on Rotation 1 in year 4

	NIAB	Rothamsted	Scottish Agricultural College
Date of herbicide application	25 September 01	1 November 01	26 November 01
Date of assessment	1 October 01	19 November 01	31 January 02
Number of quadrats/plot	20	12	10
Size of quadrats	0.25 m^2	1m^2	0.25m^2

At Brooms Barn in year 3 it was possible to record the number of volunteer rape plants in the sugar beet (Rotation 3) prior to the application of herbicides to control it. Counts were done on 25 June and 14 July and the highest value was assumed to represent the maximum number of plants. Twelve 0.5m^2 quadrats were counted on each plot. It is possible that some of the plants present in May might have died before June and so the later count would have been an under-estimate. However, it was concluded that this would only have affected a minority of plants.

The number of dying plants was compared to the nearest soil seedbank assessment; winter 2001/02 for the rape and winter 2000/01 in the sugar beet crops. Details of the methods used to measure the soil seedbank are given earlier in this Section.

4.8 Statistical Analysis of data

1. All experiments were of a factorial design with variable levels of treatments and replication. Rotation 1 at Rothamsted and SAC had four replicates, whilst the smaller Rotation 1a at NIAB had two replications. Rotations 2 and 3, all had two replications. Rotations 4 and 5 had 3 replicates. Despite the limited replication the smallest trials (Rotation 2) had 18 plots in the key final year and thus 8 df in the error, adequate for assessment of the treatment effects. Plot layouts and arrangements are described in Appendix 10.3.3.
2. Raw data, from the various rotations of the project, were collated and converted to counts per m^2 for all weed assessments, g/m^2 for biomass assessments. Weed seedbank from soil core data, counts/500g soil converted to seeds /m^2. Analyses were based at a site within a rotation and decisions were taken at a very early stage not to attempt any over site analyses within any rotation as the distribution of initial (and subsequent) weeds were known to be different at the different sites.
3. Genstat statistical software was used to undertake all statistical analyses. This system was flexible enough to deal with the complexity of the temporal design structure (where second GM events were utilised these were applied perpendicular to the initial primary GM event) and cope with missing values (zero or very few in most main rotations but they did exist within the full compass of the BRIGHT project). Further analytical complexities occurred due to the withdrawl of the 'IMI' treatment in the middle of the project, which GenStat dealt with in a practically workable manner.
4. To focus analytical and interpretative effort on the weeds of agronomic or biological importance, a threshold was initially applied to the data. While this action was likely to aid focus on the major weeds; it also immediately introduced bias in the overall analyses and in particular estimates of flux in species diversity. Thresh-holding was abandoned and all non-zero data retained, analysed and summarised.
5. Concerns about the spatial variability of the weeds within sites led us to explore the potential of applying covariates to the data. The original aim was to apply a suitable covariate, based on 'initial' pre-treatment assessments, to other treatments to standardise the effects to a common density. Both the initial seed

core/weed seedbank data and the autumn (Year 1) pre-treatment were available but both suffered from the same set of limitations. Firstly, there were cases where suitable weeds in the seed cores or autumn count (Year 1) existed but these weeds were not observed in the rest of the experiment (specific rotation and site). Secondly there were cases where the potential covariate had no records for weeds that subsequently were observed. There were also cases where the analysis without covariates showed statistical differences between treatments which failed to achieve significance when covariates were included. While the latter point is a desirable one (reducing the risk of a 'false positive' through application of an appropriate analyses/covariate) it was necessary to note such cases for consistency of interpretation – in many scientific studies, a non-significant result can be just as meaningful as a statistically significant one.

6. Where possible in the main R1 and R3 rotations, analysis using both potential covariates was conducted, but the adjusted treatment means, adjusted for covariates, were only used where the covariate had statistically significant effects.
7. After considerable evaluation of the quality of the data and results of preliminary analysis, all of the weed count data was analysed both as **x** raw counts / m^2 and transformed $\log_{10}(\mathbf{x}+1)$ [catering for zero counts]. The former as an aid to interpretation. Transformation was applied to the lowest strata of experimental unit - the subplot.
8. Data for weed seedbanks were subjected to both raw and $\log_{10}$ transformation but were generally reported in raw counts.
9. For temporal analyses post the primary GM event, the analyses took into account the hierarchical structure of rotation, replicate, plot and sub-plot. Where a second GM event occurred analyses were undertaken based on the initial GM event (carry over effect); the secondary GM event and a 'crossed' analysis where the treatment interaction between 'primary' and 'secondary' GM events were assessed and tested statistically.
10. In all analyses the treatment means and appropriate SED's and LSD's are summarised.
11. Appropriate cross site analysis was discussed, but because of the variability between sites it was decided that this should not be included as part of these initial analyses. More detailed analysis, including variation in 4 year weed trajectories in response to the treatments and multi site comparisons were beyond the scope and resources of this project but are planned for the future using new resources.

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Chapter 5.1 (Pages 41 - 79)

5. RESULTS - Weed control

This section of the report starts with a general overview of the weeds present on the five sites and of the weed control. It then gives detailed reports of the weed control achieved by the treatments on the five rotations in each of the four years and provides results of changes in the seedbank for the main rotations 1, 2 and 3. Species diversity is reported for Rotation 1. It includes crop yield data for sugar beet but oilseed rape yield data are presented at the beginning of Section 6 on volunteer oilseed rape.

The performance of the herbicides used in this programme was monitored in all years, at all sites. The key measurements were counts of weed density prior to treatment, counts after treatment and a weed biomass assessment at the end of the cropping season. In the oilseed rape based rotations the weed counts were generally done in the autumn and spring but where spring crops were included all counts were done in the spring and summer. The philosophy was that the pre-treatment counts gave an estimate of the level of weed infestation, the post treatment counts indicated the level of performance of the herbicides and this was supported by the biomass data, which also indicated the level of seed return by the weeds. These three basic assessments were supported when necessary by subjective visual assessments of herbicide activity and other measurements on the crop and/or weed.

Initial statistical analyses indicated that the distribution of the data was clearly skewed, with many plots with fewer weeds and a minority with many. Consequently, it was decided that the weed data should be logarithmically transformed to equalise the variation in the data. Thus, the majority of the results presented are of Log10 transformed means and their associated standard errors. The consortium has also spent a considerable amount of time and effort on resolving the issue of the spatial aggregation of weeds. As the plots in this programme tended to be large, each experimental covering several hectares, the weeds tended not to be evenly distributed across the sites. There was then a risk that erroneous conclusions could arise, due to this spatial variation in the weeds. The data from several of the sites have been analysed using covariates to remove any effects of spatial aggregation. This was done by using both the seedbank data collected at the start of the programme and the weed counts done prior to herbicide treatment in year 1. Any variation in either of these data sets would indicate spatial variation. Having analysed subsequent weed data, using these two covariates we found that for some weeds, at some sites, the covariates had a statistically significant effect. However, having looked more closely at the impact of the covariates it was evident that their effects on the treatment means and on significant differences between treatments were small. Some means increased and others decreased, but there was little indication that the conclusions from the raw data were invalidated when the data were re-analysed with the covariates. Thus, the results presented are not adjusted using the spatial aggregation covariates.

All weeds were assessed on all the plots and individual species were identified. Between 18 and 53 species were identified at each site over the four years of the experiment (See Appendix 4. Section 10.4 Table 10.4.1.). However, many of the species occurred only rarely and their densities were so low as to make treatment comparisons impossible. Others were only present in a minority of years. Hence the main analyses focussed on a restricted number of the commoner species. All the weeds present were included in the 'total weeds' parameter and a further parameter of 'total weed species' was also estimated for each plot. From this a calculation was made of the effect of the treatments on botanical diversity.

Impact of the herbicide treatments on WOSR and sugar beet

Some yellowing of glufosinate tolerant beet was observed following treatment with glufosinate at Broom's Barn and Morley in Rotation 2. In addition some conventional beet showed transient chlorosis after treatment (Section 5.2). The chlorosis probably delayed establishment and might have marginally reduced yields. Similar effects have been observed in other experiments and in NIAB variety trials, where HT beet was grown with conventional or with the herbicide to which it was tolerant. Generally the latter had higher beet and sugar yields than the same variety grown with conventional herbicides.

All other varieties of beet and rape were tolerant to their respective herbicides but were sensitive to other herbicides applied to HT crops, and no other phytotoxic effects were observed.

Crop growth and yields of sugar beet and winter oilseed rape

The growth of the oilseed rape cultivars was quite similar at each site. There was often some spatial variation in crop vigour as a result of variation in soil type and topography across the sites and because of spatial variability in pigeon and rabbit grazing. There was no clear evidence of a varietal component in this variation. Gross differences in the growth of the three sugar beet cultivars were not noted, except that at Brooms Barn higher levels of bird damage were recorded on the conventional crops, associated with the absence of weeds on these plots. This is explained in more detail in section 5.2.1. Some variation in the development of the WOSR was noted in England, as the imidazolinine resistant cultivar tended to start flowering earlier than the other three.

Yields were taken from most plots in all years to determine whether there were different treatment or variety effects and to evaluate the management programmes. Generally yields were above average in the oilseed rape varieties with little apparent effect of treatments on yields, since the ranking order of varieties was much as anticipated from growing the varieties in National List and other trials. Further details are given in section 6.1. Yields of beet were generally low, largely due to delayed sowing in one year and the early harvest of all trials in advance of the harvest of commercial crops. The early harvest was a requirement of the DEFRA consent to grow the crop. Data on beet yields are provided in the results of each of the rotation experiment.

5.1 Rotation 1 (oilseed rape – cereals – cereals – oilseed rape)

5.1.1 Rothamsted

The main weeds to occur on Rotation 1 at Rothamsted were *Aethusa cynapium* (AETCY – fools parsley), *Avena sativa* (AVESA – oats), *Brassica napus* (BRANA - oilseed rape), *Papaver rhoeas* (PAPRH - common field poppy), *Senecio vulgaris* (SENVU – groundsel), *Stellaria media* (STEME – common chickweed), *Triticum aestivum* (TRIAE – wheat), *Veronica persica* (VERPE – common field speedwell) and *Viola arvensis* (VIOAR – field pansy). A further 35 species were also present in some years and some assessments, but only at low density.

Year 1 Oilseed rape

The four herbicide treatments were applied to the rape in the autumn of 1998. Weeds were already present, especially prior to the later applications of glyphosate and glufosinate (Table 5.1.1.1). The commonest weed was volunteer oats from the previous crop of oats harvested in summer 1998.

Table. 5.1.1.1. Density of the major weeds present on rotation 1, prior to treatment in autumn 1998

Species	Mean weed density in autumn 1998 (plants/m^2)
Aethusa cynapium	0.1
Avena sativa	26.9
Papaver rhoeas	5.2
Senecio vulgaris	4.5
Stellaria media	6.0
Veronica persica	1.4
Viola arvensis	12.3
Total weeds	57.2

Following application of the four herbicide treatments (imazamox, glyphosate, glufosinate and conventional (metazachlor + cycloxydim)) significant differences were recorded in the following spring. Overall, significantly fewer weeds were present on the glyphosate treated plots (Fig 5.1.1.1.). This was primarily due to significantly higher control of oats and *S. vulgaris*. Glufosinate was least effective on the oats. The conventional treatment was least effective on *S. vulgaris* but most effective *V. persica*. Thus, there appeared to be some variation between species in the level of sensitivity.

Later in the year the biomass assessment indicated a similar pattern though the level of treatment significance had declined. Overall there was least biomass on the glyphosate treated plots (Fig. 5.1.1.2). This is reflected in generally less individual species after this treatment, although significant treatment effects were only detected on the oats and *P. rhoeas.* Interestingly, poor long-term control of oats by imazamox led to these plots having the most weeds. The poor oat control by glufosinate was again apparent. However it should be noted that the overall mean weed weight on the plots was only 22 g/m^2, which is low in context of weeds in rape, where at this time of the year the crop can weigh over 1000 g/m^2. Consequently, crop yields were not likely to be reduced by the presence of weeds. Indeed, highest yields (Section 6.1) were on the glufosinate and conventional rape plots, supporting the view that there was no correlation between yields and the overall weed biomass in Fig. 5.1.1.2.

Year 2 - winter wheat

In year 2 the plots were planted with winter wheat. They were treated uniformly, all receiving a standard weed control programme (Section 10.2 Appendix 2). However it was possible that the impact of the different weed control treatments in autumn 1998 would have carried over into year 2. Weed densities in general were low in autumn 1999. The mean density was 67 $plants/m^2$ and the flora was dominated by *P. rhoeas* and *V. arvensis*. No significant effects of the previous treatments were detected. In the following spring the surviving weeds are shown in Fig. 5.1.1.1.

In general, there were no marked differences between the weeds on the plots receiving the four treatments in year 1, although there was a significant response recorded for *V. persica*. Weed biomass in summer was very low (mean 2.8 g/m^2) and no differences between the treatments were detected (Fig 5.1.1.2).

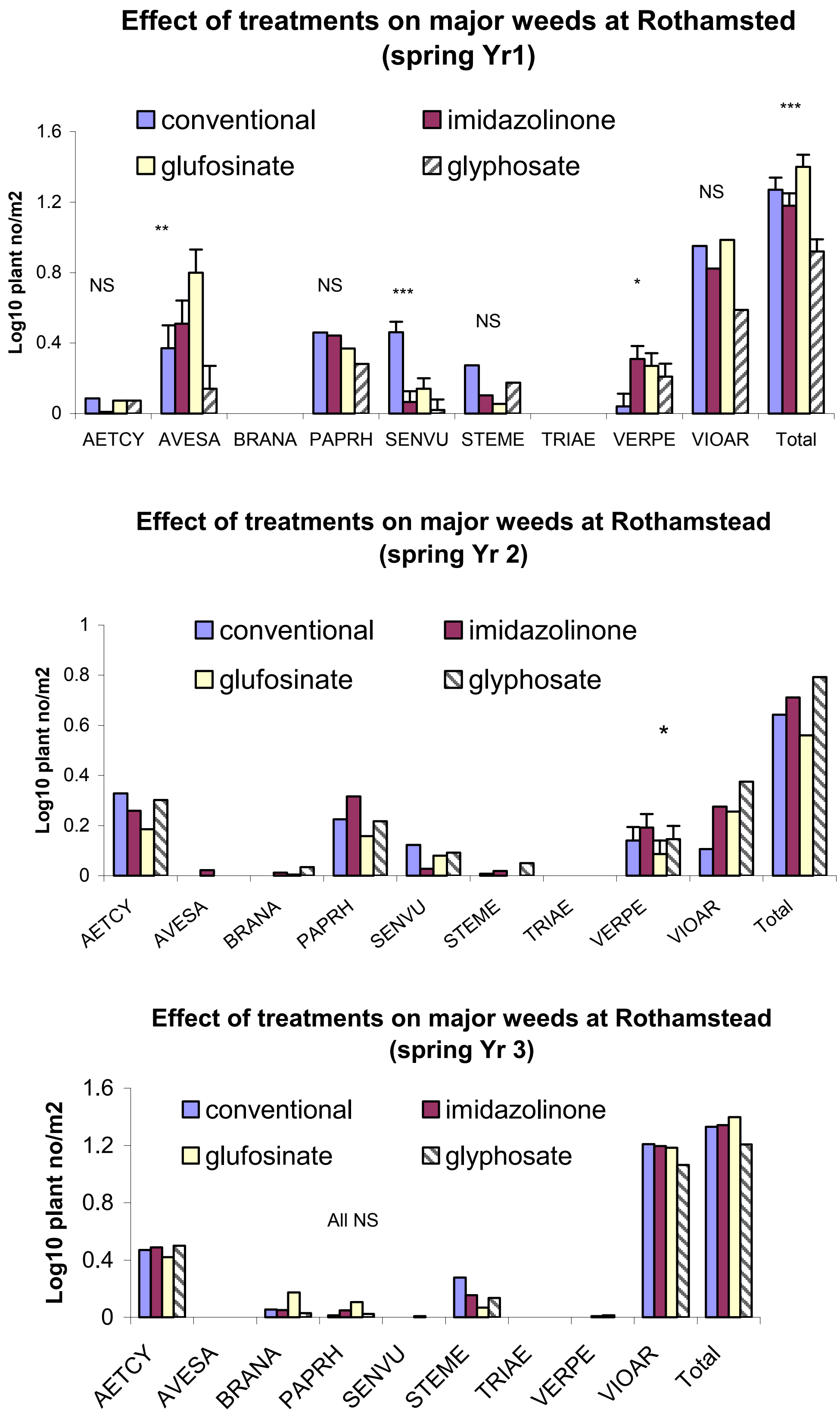


Figure 5.1.1.1. Rotation 1 at Rothamsted : The response of weeds in years 1-3 respectively, to the herbicide treatments in year 1: spring assessment of weed density (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001: Vertical bars = 1x SED).

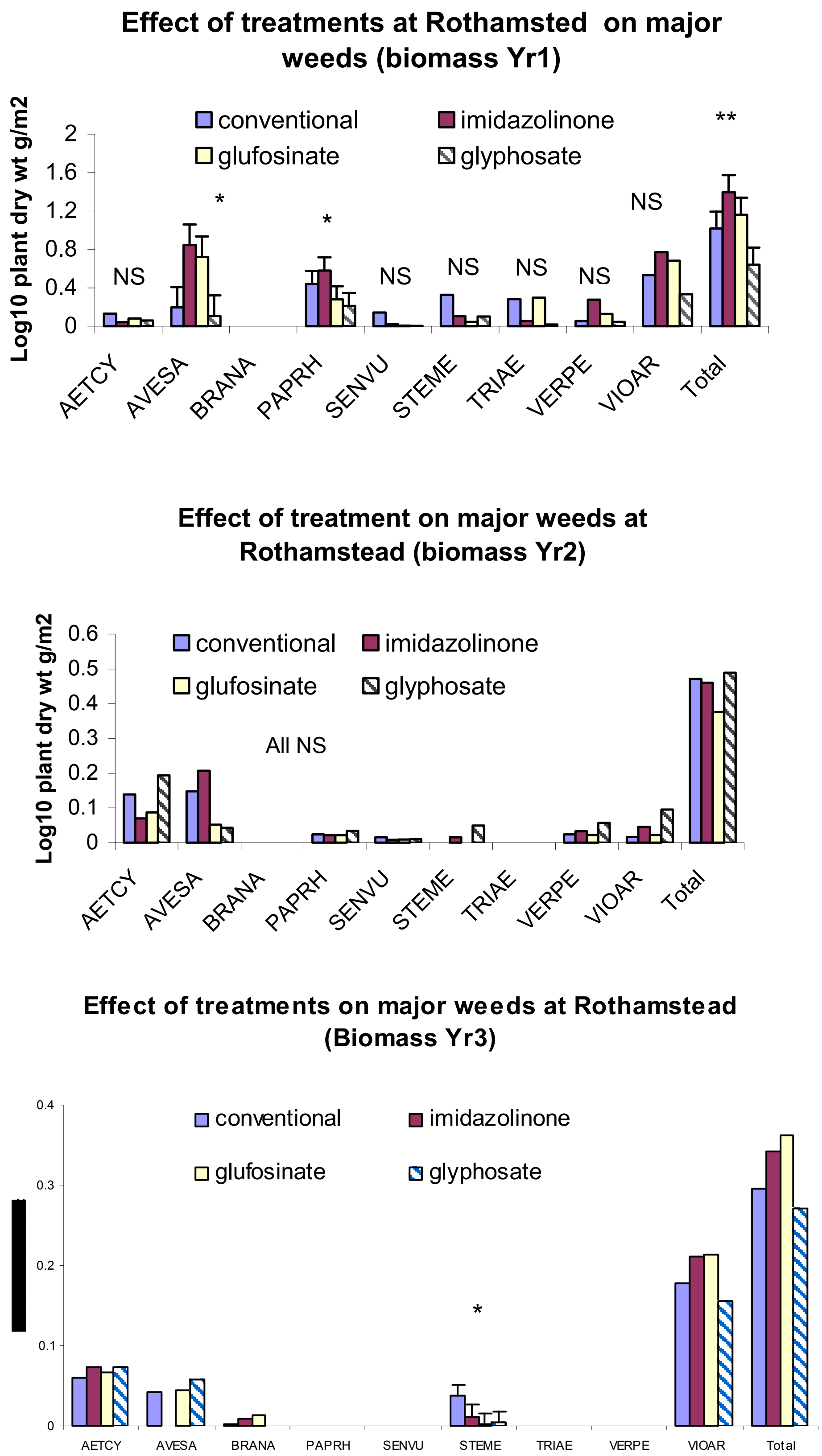


Figure 5.1.1.2 Rotation 1 at Rothamsted : Response of weeds in years 1-3 to the herbicide treatments in year 1: biomass assessment in summer (NS = no significant effect of treatment: stars = significance * p<0.05: Vertical bars = 1x SED).

Year 3 - winter wheat

Autumn 2000 was extremely wet and this inhibited weed emergence. Consequently few weeds were present in the autumn (mean 76 plants/m^2). Again *P. rhoeas* and *V. arvensis* were the commonest species. These were effectively controlled by the overall herbicide treatment regime, such that mean spring weed density was only 26 plants/m^2.

No treatment effects from year 1 were apparent (Fig. 5.1.1.1). Similarly, weed biomass in the summer was very low, with a mean of 1.5 g/m^2. Treatment effects from the herbicides used in year 1 were not detected, except for *S. media* where there was marginally more weed on the former conventional plots (Fig. 5.1.1.2). A low level of volunteer rape was recorded at this assessment.

Year 4 - oilseed rape

Prior to treatment in autumn 2001 a mean weed count of 174 plants/m^2 was recorded. There was no significant difference between the densities, resulting from the treatments applied in autumn 1998. As the imidazolinone tolerant rape had been withdrawn earlier in the project, this treatment in year 4 was replaced by a second conventional treatment. At Rothamsted these plots were treated with cyanazine. As the imidazolinone treatment was no longer available, the plots treated with this herbicide in year 1 have been excluded from the year 4 analyses.

As the treatments applied in year 4 were randomised within the plots treated in year 1 the weeds present in spring year 4 could be the result of effects of treatments in year 1 or those applied in year 4. The factorial analysis showed which treatments were affecting the weed densities (Table 5.1.1.2). Low levels of significance were apparently demonstrated as a result of the year 1 treatments for *Senecio vulgaris* and *Stellaria media.* More weeds were present on the plots that had been treated with the conventional herbicides in year 1 (Table 5.1.1.3) which reflects the higher numbers of weeds in year 1 (Fig 5.1.1.1 and 5.1.1.2.). There was one significant interaction between year 1 and year 4 treatments with *S. vulgaris,* but this was not very clear and weed densities were very low (mean 0.2 plants/m^2), indicating that its biological significance was minimal. The main effects detected in year 4 were from the treatments applied in autumn 2001 (Table 5.1.1.2). Significant effects were recorded for *P. rhoeas, S. vulgaris, S. media, T. aestivum, V. persica, V. arvensis* and for the total weeds. The herbicide treatments had not been fully successful at controlling the weeds, as there was a mean of 81 plants/m^2 on the treated plots and 136 plants/m^2 on untreated quadrats placed in each plot.

Table 5.1.1.2 Statistical significance of the year 1 and year 4 treatments on weed density (Log10 plants/m^2) in spring 2002 at Rothamsted

Weed	TreatsYr1	TreatsYr4	Interaction
AETCY	NS	NS	NS
AVESA	NS	NS	NS
PAPRH	NS	***	NS
SENVU	*	***	*
STEME	*	**	NS
TRIAE	NS	***	NS
VERPE	NS	*	NS
VIOAR	NS	***	NS
Total	NS	***	NS

Table 5.1.1.3 Effect of year 1 treatments on the weeds present in spring 2002. (Log10 transformed weed density (plants/m^2)

Weed species	Treatments			Standard error of a difference between means
	conventional	glufosinate	glyphosate	
S. vulgaris	0.11	0.046	0.029	0.034
S. media	0.417	0.169	0.197	0.116

The alternative conventional treatment (conventional* - cyanazine) tended to deliver the poorest level of weed control, except for *S. media* (Fig. 5.1.1.3) Glyphosate achieved the highest level of control of *P. rhoeas*, *S. media, T. aestivum* (volunteer wheat) and *V. arvensis*. Glufosinate and the conventional treatment (metazachlor + quinmerac) demonstrated similar levels of control, though the latter was poorer on the *S. media*.

Similar analyses were done on the weed biomass data collected in June 2002. Weeds were still present on all plots although the mean of 29 g/m^2 was appreciably lower than the 56 g/m^2 collected from the untreated quadrats. As in 1999, the volume of weed present, even in the untreated areas was low compared to the 'normal' biomass of rape at this time of the year (c. 1000 g/m^2) (e.g. Leach *et al*., 1994). The factorial analysis comparing the effects of the year 1 treatments and those of the year 4 ones, clearly showed that there were only significant treatment effects detectable from the year 4 treatments, applied in autumn 2001 (Table 5.1.1.4.)

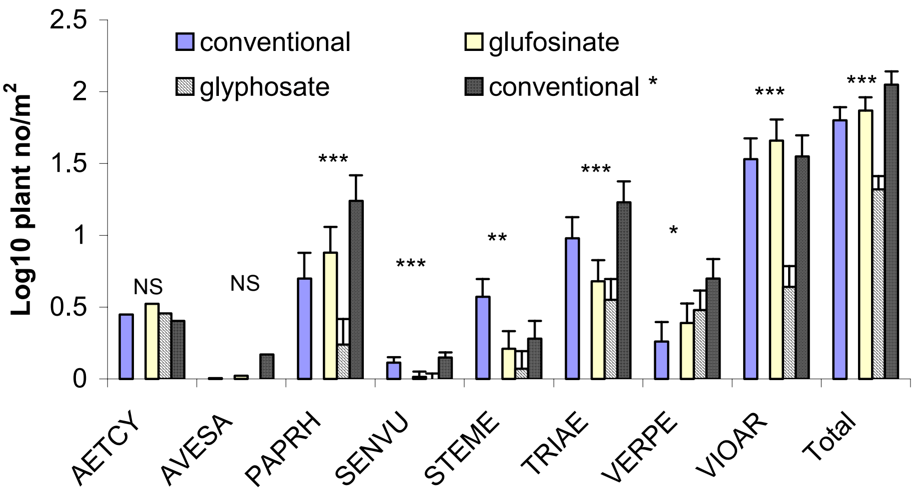


Figure 5.1.1.3 Rotation 1 at Rothamsted: Weed density in spring 2002 following the 'year 4' herbicide treatments applied in autumn 2001 (NS = no significant effect of treatment: stars = significance *p<0.05, ** p<0.01, ***p<0.001: Vertical bars = 1x SED).

Table 5.1.1.4. Statistical significance of the year 1 and year 4 treatments on weed biomass (Log10 g/m^2) in summer 2002 at Rothamsted

Weed	TreatsYr1	TreatsYr4	Interaction
AETCY	NS	*	NS
AVESA	NS	NS	NS
AVEFA	NS	*	NS
PAPRH	NS	NS	NS
STEME	NS	NS	NS
TRIAE	NS	***	NS
VERPE	NS	NS	NS
VIOAR	NS	***	NS
Total	NS	***	NS

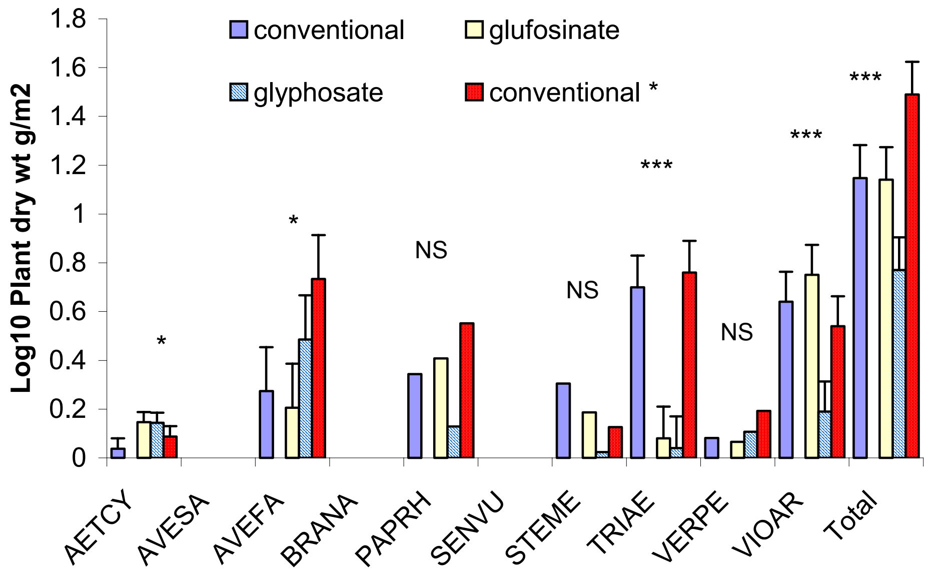


Figure 5.1.1.4 Rotation 1 at Rothamsted: Weed biomass in summer 2002 following the year 4 herbicide treatments applied in autumn 2001. (NS = no significant effect of treatment: stars = significance *p<0.05, ** p<0.01, ***p<0.001: Vertical bars = 1x SED)

Significant effects of the treatments were recorded on four species and on the total weed biomass (Fig 5.1.1.4). The poor control of A *.fatua* by the alternative conventional treatment (cyanazine) generated the highest biomass of this species, but late emergence on plots treated with glyphosate resulted in appreciable weight of this weed after this treatment. Glufosinate achieved the best control. Quantities of *A. cynapium* were small and so the magnitude of the treatment differences, in biological terms, was small. Volunteer wheat was not controlled by either of the two conventional treatments but was fully controlled by glyphosate and glufosinate. *V. arvense* was well controlled by glyphosate but not by the other three treatments. Overall, glyphosate achieved the best control and the conventional* (cyanazine) was least effective.

Conclusions – Rothamsted

Weed control was uniformly high in the two cereal years (years 2 and 3) and so differences due to the treatments were mainly apparent in the two oilseed rape years, where the four treatments were applied. There was little evidence that the varying levels of weed control apparent in year 1 were influencing weed infestations in subsequent years. Some statistically significant differences were detected but these differences were small and no consistent pattern was discernible. The main treatment differences were detected on the weeds in the rape crops treated with the four herbicides (years 1 and 4). Overall, glyphosate achieved the highest level of weed control and either the imidazolinone (year 1) or the conventional * (cyanazine) (year 4) were the poorest. The glufosinate and conventional treatments (based on metazachlor) achieved similar levels of control.

Weed densities were sufficient to warrant treatment, if only to prevent weed increase through seed production, especially in the parts of the trial where the rape was less vigorous. None of the treatments achieved full weed control but the quantities surviving in summer 1999 and 2002, even following the poorest treatment, were unlikely to affect rape yields. In 2002 the value of a competitive crop was clearly demonstrated by the data from the untreated quadrats, as mean summer weed weights were only 22 g/m^2 on the vigorous part of the experiment and 91 g/m^2 on the less vigorous part.

Weed biomass in the cereal years was lower than in any of the treatments in the oilseed rape years (see Fig. 5.1.1.5).

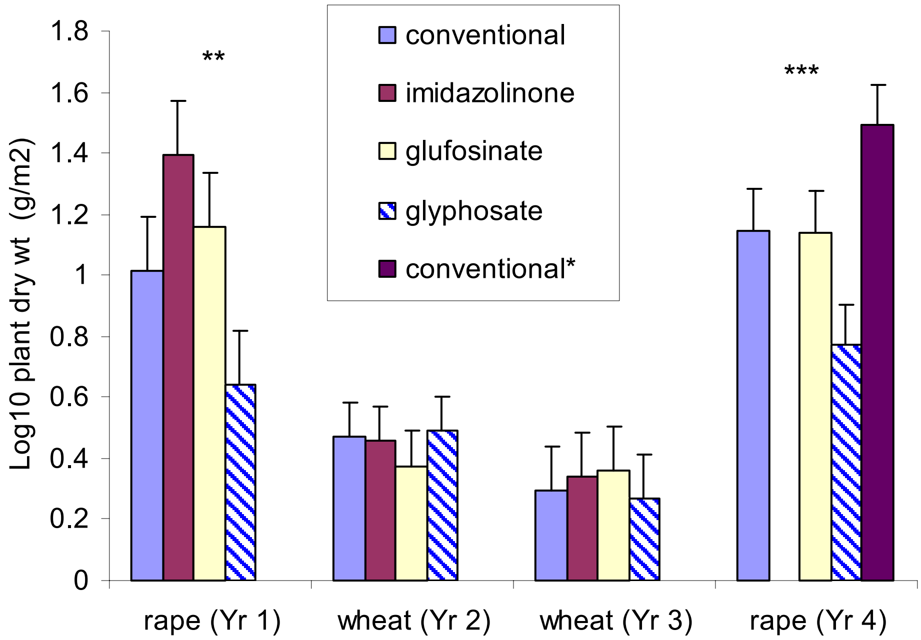


Figure 5.1.1.5. Rotation 1 at Rothamsted: Overall biomass of weeds in summer in the four years. The treatments were only applied to the plots in years 1 and 4. (significance, **p<0.01*p<0.001: Vertical bars = 1x SED)**

5.1.2 Scottish Agricultural College (SAC) Rotation 1a and 1b.

The main weed present at SAC was *Poa annua* (POAAN - annual meadow grass), but substantial quantities of *Stellaria media* (STEME - chickweed), *Myosotis arvensis* (MYOAR - field forget me not), *Matricaria* species (MATsp – mayweed the population comprised of both *Matricaria perforata* – scented mayweed and *Matricaria discoidea* - rayless mayweed) and *Viola arvensis* (VIOAR - field pansy) were also present. Where data on other grass species have been presented the population comprised of varying densities of *Agrostis gigantea* – black bent, *Avena fatua* - wild oats, *Elymus repens* – couch grass, *Holcus lanatus* – yorkshire fog, *Holcus mollis* - creeping soft grass, *Phleum pratense* – timothy.

Year 1 oilseed rape

Four herbicide treatments were applied to the rape in autumn 1998. The main weeds present prior to treatment are shown in Table 5.1.2.1. The commonest weeds were *P. annua* and *S. media*. The statistical analysis showed there was a significant effect of the treatments on *Capsella bursa-pastoris* prior to herbicide treatment ($p<0.05$). However the density of this weed across all treatments was extremely low (overall mean of 0.13 plants/m^2).

Visual weed assessments were carried out in the spring, the results showed that overall there were very few weeds present. The main weeds were *Matricaria* spp., *P. annua*, *S. media*, *V. arvensis* and *Hordeum vulgare*. *Hordeum vulgare* was most common on the conventional herbicide treated plots, as the treatments of metazachlor and benazolin + clopyralid are weak on this species. Plots treated with imazamox had the highest density of *P. annua* and *Matricaria* spp.. It was noted that the glufosinate treated plots gave the highest level of weed control.

Table 5.1.2.1 Density of the major weeds present on Rotation 1a and 1b prior to treatment in autumn 1998

Species	Mean weed density in autumn 1998 (plants/m^2)
Poa annua	181.8
Matricaria sp.	9.0
Myosotis arvensis	11.1
Stellaria media	32.3
Viola arvensis	15.2
Total weeds	255.0

The summer biomass assessment showed that the glufosinate treatment produced significantly less weed biomass overall, reflecting the observations made in the spring. The imazamox treatment produced the highest levels, due to the high density of grass weed species present and the high density of *Matricaria* species which approaches significance (Fig. 5.1.2.1.). Conventional and glyphosate treated plots produced similar total levels of weed biomass. The mean weed biomass across all plots was 32.2 g/m^2.

Significant differences were recorded for three of the main weed species, *M. arvensis*, *S. media* and *V. arvensis* (Fig. 5.1.2.1.), all were controlled most effectively by the glufosinate treatment and *Viola arvensis* was controlled least well on the conventional plots. Significant differences between treatments were also demonstrated for *H. vulgare* (p<0.01) and other grass species (p<0.001) (especially *Holcus lanatus*) in both cases the glufosinate treatment gave superior control.

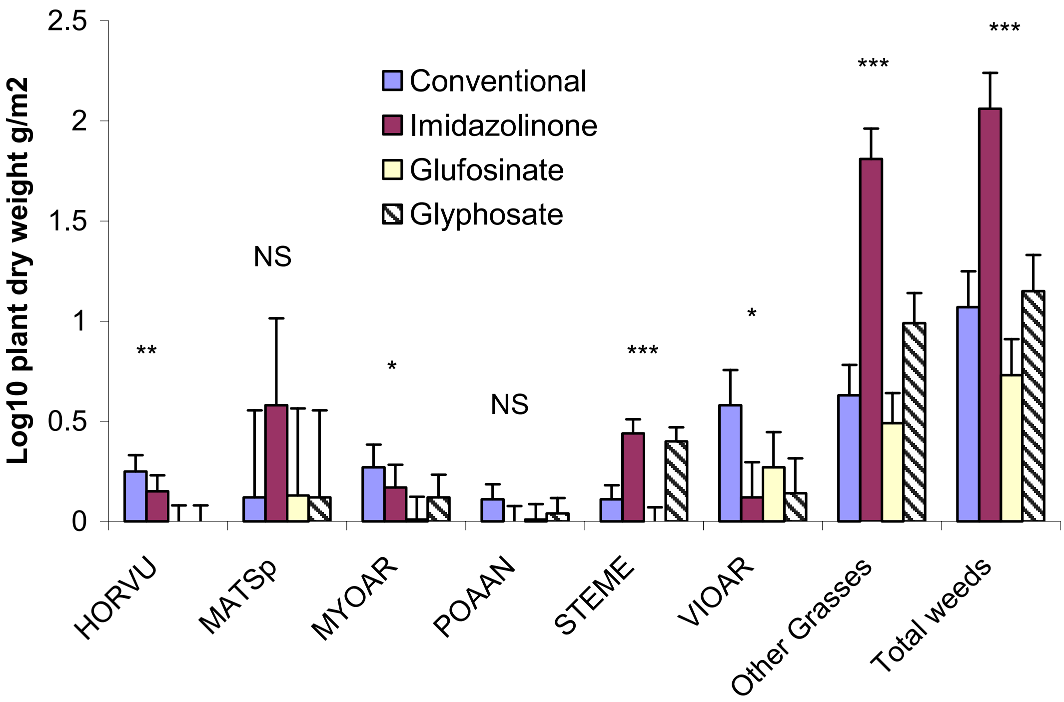


Figure 5.1.2.1 SAC rotation 1a and 1b : Response of weeds in year 1 to the herbicides applied in year 1: weed biomass assessment in summer (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

Year 2 - Winter barley

In year two the plots were planted with winter barley. Weed numbers were very low in autumn 1999 due to dry conditions at sowing so the decision was taken not to spray with herbicide, thus no autumn weed count was carried out. A visual assessment of weeds showed that *Brassica napus* volunteers were present in several areas across the field.

A spring weed count showed that weeds had emerged in the crop over winter and early spring resulting in an overall mean of 28 plants/m^2. *Poa annua* was the most common weed (23.3 plants/m^2), *S. media* was the only other weed recorded at an average density of >1 plant/m^2 (2.5 plants/m^2). No significant effects from the previous years rape treatments were detected. The weeds recorded in the spring weed assessment are shown in Fig. 5.1.2.2.

Weed biomass in the summer was also very low with a mean of 3.1 g/m^2. The main weed present was *P. annua*. No significant treatment effects from the previous years treatments were evident.

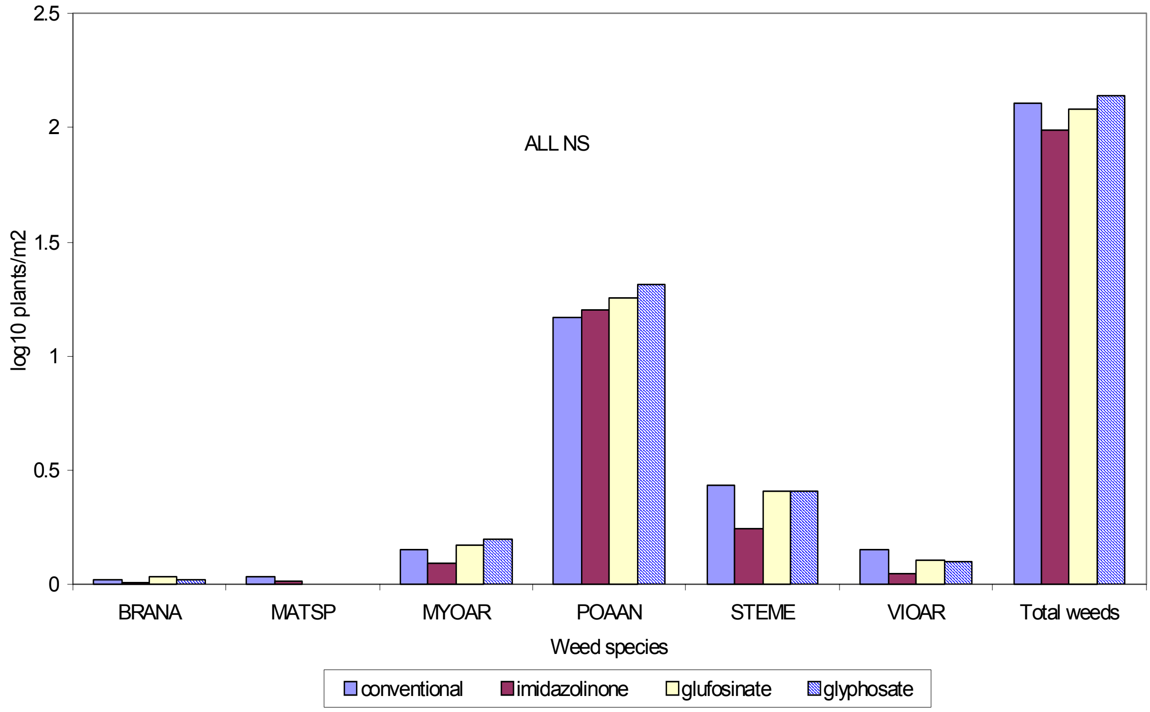


Figure 5.1.2.2 Rotation 1a and 1b at SAC: Response of weeds in year 2 to the herbicides applied in year 1 : spring assessment of weed density (NS = no significant effect of treatment)

Year 3 - Winter barley

In common with year 2 the weed numbers were very low in autumn and no herbicide was applied to the field. A visual assessment of weeds showed that the weed species present were *M. arvensis, P. annua, S. media*, and *B. napus*.

The spring weed count showed that the most common weeds were *Matricaria* spp., *P. annua, S. media*, *V. arvensis*, and *B. napus* volunteers. The overall mean weed density was high due to no herbicides being applied (148 plants/m^2). Significant differences in densities of the main weeds present were detected between the former oilseed rape treatments (Fig. 5.1.2.3.), with most weeds being present on the former imidazolinone treated plots.. There was a significant difference between levels of *B. napus* ($p<0.001$); plant densities ranged from 3 plants/m^2 in the former glyphosate treatment to 24 plants/m^2 in the glufosinate treated plots. It was also noted that the higher numbers of *B. napus* volunteers were recorded in rotation 1b plots where plots were cultivated sooner after crop harvest than they were in the other rotation.

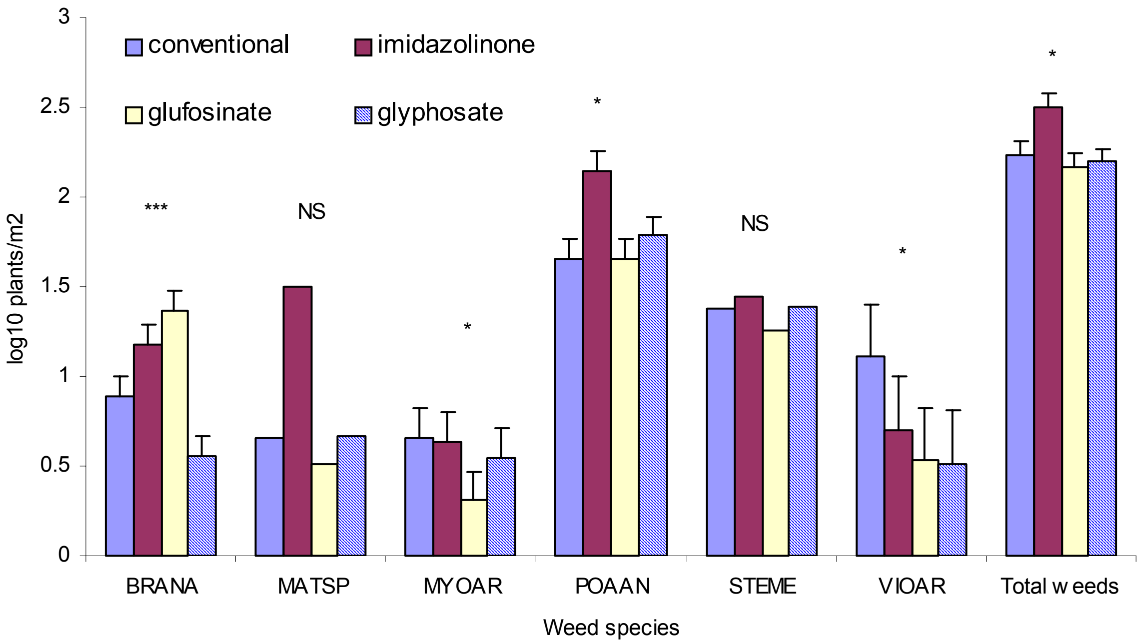


Figure 5.1.2.3. Rotation 1a and 1b at SAC: Response of weeds in year 3 to the herbicides applied in year 1: spring assessment of weed density (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

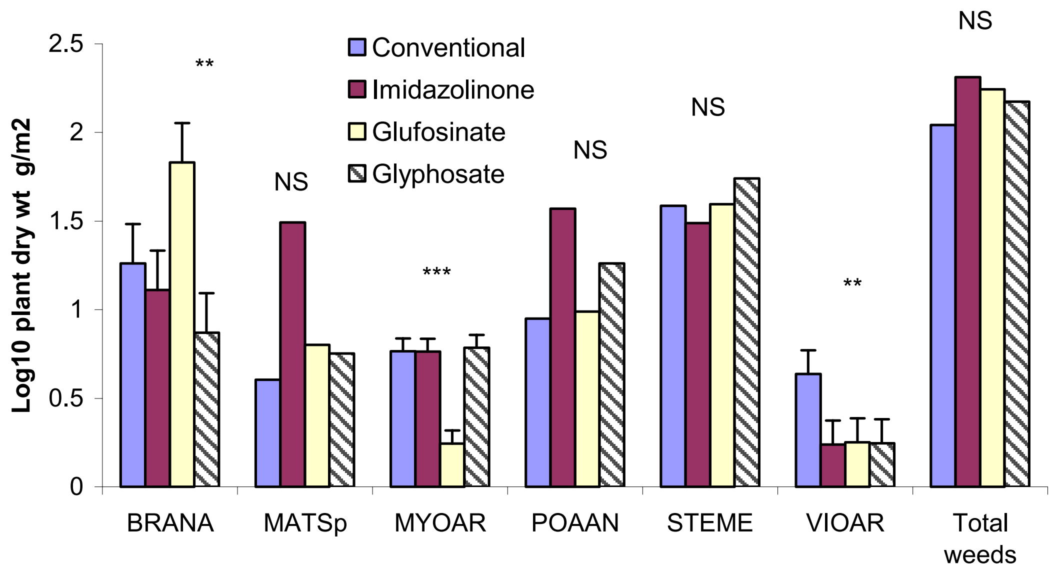


Figure 5.1.2.4. Rotation 1a and 1b at SAC: Response of weeds in year 3 to the herbicides applied in year 1: biomass assessment in summer (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

The relatively high spring counts of weeds were reflected in the biomass assessment as no herbicide had been applied (overall mean of 165 g/m^2) it was noted that high numbers of flowering weeds were present. There were significant effects evident from the year 1 treatments. The biomass of *B. napus* was significantly greater on the glufosinate treated plots ($p<0.01$), reflecting the high levels observed on these plots in the spring. Significant treatment effects were also demonstrated for two of the other main weeds, *M. arvensis* and *V. arvensis*. Responses to the treatments were similar to those recorded earlier in the weed counts. High biomass of *Polygonum aviculare* was also recorded in all treatments (overall mean 27 g/m^2). In common with the previous year, the former imazamox treated plots produced the highest weed biomass.

Year 4 - Winter oilseed rape

In autumn 2001 a mean weed density of 466 plants/m^2 was recorded. The main weed species present were *P.annua, S. media, Matricaria* sp., *V. arvensis*, *M. arvensis* and *H. vulgare*. The imidazolinone treatment was replaced by a second conventional treatment (propyzamide). As the imidazolinone treatment was no longer available the plots treated with this herbicide in year 1 have been excluded from the year 4 analyses.

Table 5.1.2.2 Statistical significance of the year 1 and year 4 treatments on weed density (log10 plants/ m^2) in spring 2002

Weed	TreatsYr1	TreatsYr4	Interaction
Matricaria sp.	NS	**	NS
Myosotis arvensis	NS	*	NS
Poa annua	NS	NS	NS
Stellaria media	NS	NS	NS
Viola arvensis	NS	*	NS
Total	NS	NS	NS

The spring weed counts showed that the overall weed density was 115 plants/ m^2. The main effects in year 4 were from the herbicides applied in the previous autumn 2001 (Table 5.1.2.2). Significant effects were recorded for *Matricaria* sp., *M. arvensis* and *V. arvensis* (Fig. 5.1.2.5). The highest weed density was recorded in the conventional treatment, mainly due to a high density of *V. arvensis* compared to other treatments. The glyphosate treatment tended to give the best weed control. The factorial analysis showed no interaction between year 1 and year 4 treatments for any of the weed species recorded.

Table 5.1.2.3 Statistical significance of the year 1 and year 4 treatments on weed biomass (log10 g/m^2) in summer 2002

Weed	TreatsYr1	TreatsYr4	Interaction
Matricaria sp.	NS	NS	NS
Myosotis arvensis	NS	NS	NS
Poa annua	NS	NS	NS
Stellaria media	NS	NS	NS
Viola arvensis	NS	NS	NS
Total	NS	*	NS

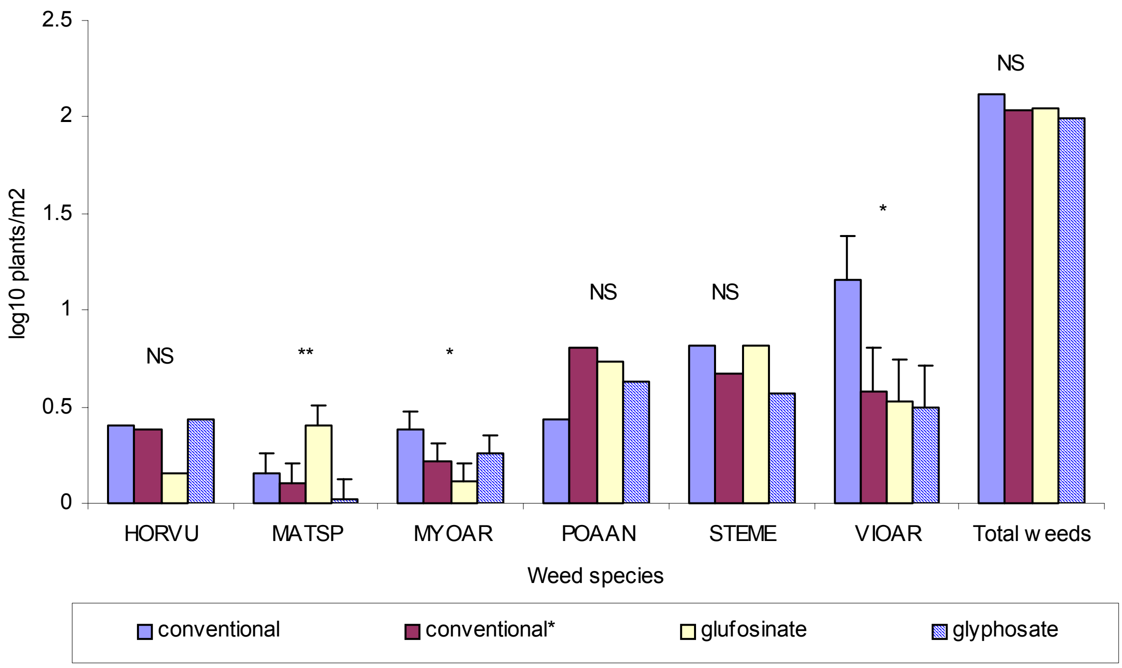


Figure 5.1.2.5 Rotation 1a and 1b at SAC : Response of weeds in year 4 to the herbicides applied in year 4: spring assessment of weed density (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

Biomass assessment in June 2002 showed that weeds were still present on all plots; the mean weed biomass was 36 g/m^2, indicating that weed survival was relatively low. There were significant treatment effects as a result of the year 4 treatments (Table 5.1.2.3.) only for the total weeds. Both the conventional and glyphosate treatments produced high total biomass values. There were indications that the conventional plots contained high densities of *H. vulgare* and *Holcus lanatus*. The aggregated distribution of *H. lanatus* in the field most probably produced this effect. High biomass of *H. vulgare* was also present in the glyphosate treatment and contributed to the high total biomass in this treatment. In contrast to the high spring weed count, the glufosinate treatment produced the least weed biomass. The factorial analysis showed no interaction between year 1 and year 4 treatments for any of the main weed species (Table 5.1.2.3).

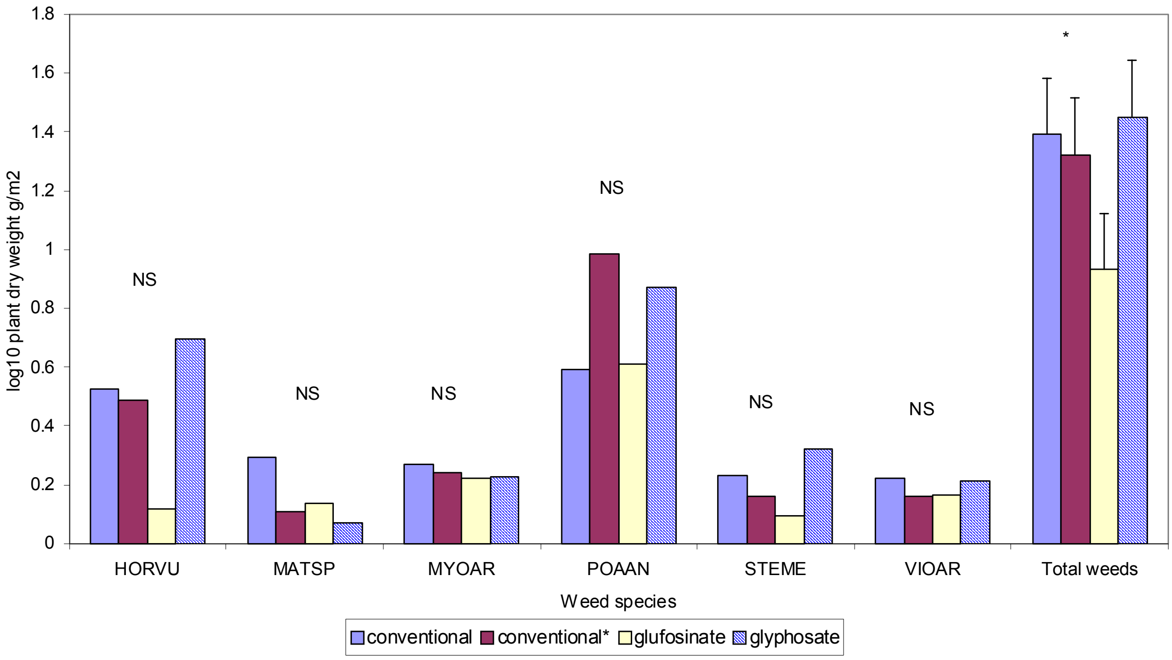


Figure 5.1.2.6 Rotation 1a and 1b at SAC : Response of weeds in year 4 to the herbicides applied in year 4: weed biomass assessment in summer (NS = no significant effect of treatment; stars = significance *p<0.05, vertical bars = 1 x sed)

Conclusions - Scottish Agricultural College

In year 1 glufosinate treatments had the lowest weed biomass and tended to give superior control of the various graminaceous weed species present. The conventional and glyphosate treatments achieved similar levels of weed control. Imazamox gave poorest control of weeds in year 1 and seemed to have effects on the weeds in the wheat crops in years 2 and 3 giving higher weed numbers though the results are mostly non-significant.

No herbicides were applied in years 2 and 3 in the winter barley crops due to dry conditions in the autumn which restricted weed emergence. In year 2 weed numbers were very low throughout the growing season, the former rape treatments did not appear to be significantly influencing weed densities. In year 3, the weed density increased considerably in the spring with several significant effects recorded in relation to the year 1 rape treatments. The poorer weed control recorded in the imazamox treatment in year 1 of the rotation seemed to be reflected in the year 3 winter barley crop although the effects were mostly non-significant.

In year 4 the glufosinate treatment again gave the most effective weed control overall as shown by the lower summer biomass results. Although the differences were non-significant the glyphosate treatment apparently gave less effective control of grass weeds (*P. annua, Hordeum* volunteers and *H. lanatus*), although the effect was mainly due to patchy populations of *H. lanatus.*

Weed biomass in summer was appreciable in both rape years but was even greater in year 3, winter barley, due to lack of herbicide treatment (mean weed biomass Yr 1 = 32.2, Yr 2 = 3.1, Yr 3 = 165, Yr 4 = 36 g/m^2). This result indicates how significant decisions on weed control can be over the longer term. The decision not to treat in year 3 was clearly wrong and resulted in a massive increase in weed numbers in the seedbank (Section 5.1.5). There was also a level of seed return from volunteer rape in this year impacting on the numbers in the seedbank.

5.1.3 NIAB Rotation 1

The main weeds that occurred consistently at NIAB on Rotation 1 were *Alopecurus myosuroides* (ALOMY - black-grass), *Anagallis arvensis* (ANGAR - scarlet pimpernel), *Galium aparine* (GALAP - cleavers), *Sonchus* sp. (SONsp - sow thistle) and *Triticum aestivum* (TRIAE - wheat volunteers).
Black-grass was the main weed overall there were generally very few other weed species present on this site.

Year 1 - oilseed rape

The four herbicide treatments were applied to the rape in autumn 1998. The main weeds present prior to treatment are shown in Table 5.1.3.1. The commonest weeds were *T. aestivum* (volunteer wheat) arising from the previous crop of wheat harvested in summer 1998 (overall mean density of 15 plants/m^2) and *A. myosuroides* (overall mean density of 3 plants/m^2). Generally there were very few broadleaved weeds present on this site, though a number of species occurred rarely on some plots. The most common species at this assessment was *A. arvensis.* A significant difference was demonstrated between *T. aestivum* densities recorded on plots prior to herbicide treatment ($p<0.05$).

Table 5.1.3.1. Density of the major weeds present on Rotation 1 prior to treatment in autumn 1998

Species	Mean weed density in autumn 1998 (plants/m^2)
Alopecurus myosuroides	3.16
Anagallis arvensis	2.41
Galium aparine	0.69
Matricaria sp.	0.28
Sonchus sp.	0.28
Triticum aestivum	15.48
Total weeds	22.7

In the following spring, after the four treatments had been applied, few weeds were present and the mean density was only 4.9 plants/m^2. At the spring assessment date the conventional treatment of metazachlor followed by fluazifop-butyl had controlled the grass weeds particularly well, whilst it was apparent that there was significantly poorer control of the main grass weeds *T. aestivum* and *A. myosuroides* in the glufosinate treatment (Fig. 5.1.3.1). Very low densities of both of these weeds were recorded in all the other treatments. Analysis of the Log10 transformed data demonstrated some significant differences between the treatments. There were no other major differences between the treatments due to the very low numbers of weeds present.

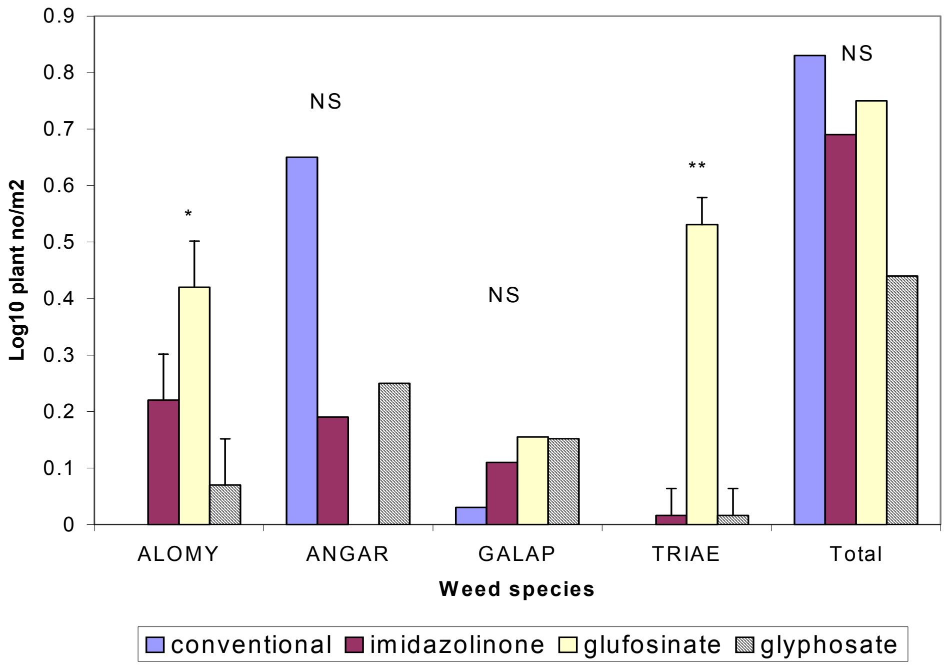


Figure 5.1.3.1. Response of weeds in rotation 1 at NIAB to the herbicides applied in year 1: spring assessment of weed density (NS = no significant effect of treatment; stars = significance *p<0.05, vertical bars = 1 x sed)

In the total weed counts, the apparently poorer control of *Anagallis arvensis* by the conventional treatment appears to have masked the better control of the grass weeds. The same pattern of responses was seen in the weed biomass assessment later in the summer. (Fig. 5.1.3.2.). There was good control of the grass weeds by the conventional treatment and poorer control from the glufosinate. Glyphosate treatment produced the least weed biomass and the imazamox and conventional treatments produced the highest total weed biomass. The overall mean weed dry weight across all plots was 37 g/m^2.

Other weeds were also recorded (data not shown). The conventional and imidazolinone treatments were much less effective on the volunteer beans (*Vicia faba*). Significant treatment effects were also recorded on *Picris echioides* (overall mean 3 g/m^2) due to poorer control in the imazamox treatment and also *Atriplex patula*, although levels were extremely low and of low biological significance. Overall weed biomass was lowest on the glyphosate treated plots, mean total weed weight was 37 g/m^2. The imidazolinone treatment was significantly less effective than the other three.

Significant differences between the yields were detected, with the lowest yields being recorded for the imazamox tolerant variety (Figure 6.1.1.1).

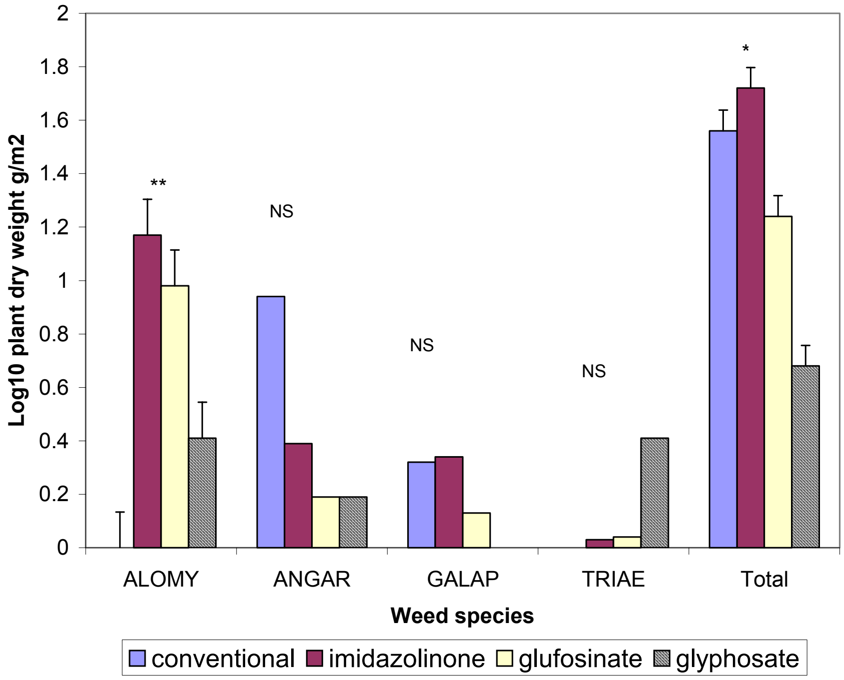


Figure 5.1.3.2 Response of weeds in rotation 1 at NIAB to the herbicides applied in year 1: biomass assessment in summer (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

Years 2 and 3 - Winter wheat

Weed numbers tended to be low in both the cereal years. Autumn and spring total weed densities were less than 0.25 plants/m^2 and 1 plant/m^2 respectively in year 2, and 7 plants/m^2 and 8 plants/m^2 in year 3. The pendimethalin based weed control programme had been effective. In both years *B. napus* (overall mean density 0.07 plants/m^2) and G. *aparine* (overall mean density 0.08 plants/m^2) plants were present. These were treated post-assessment in late spring with a further herbicide application. The biomass measurements in mid-summer were dominated by low levels of *A. myosuroides*, but overall these only reached 15 g/m^2 in year 2 and 3.4 g/m^2 in year 3.

However, the poor control of weeds in year 1 by the imidazolinone and glufosinate treatment, especially *A. myosuroides*, resulted in significantly greater total numbers of weeds following these treatments in year 2, though there were no significant differences for *A. myosuroides* alone (F-probability value 0.085). Significantly greater amounts of this weed occurred in the former glufosinate treated plots in year 3, though total weed numbers were not significantly different, (F-probability = 0.058) (Fig. 5.1.3.3).

When using autumn year 1 as a covariate, the significance in biomass year 3 is lost, suggesting that the effects of treatment in year 3 are perhaps not straightforward and may be related to the original distribution/density of *A. myosuroides* in plots prior to treatment in year 1. A low level of *B. napus* was recorded at the biomass assessment in year 3 although no plants flowered or set seed (overall mean of 0.13 g/m^2).

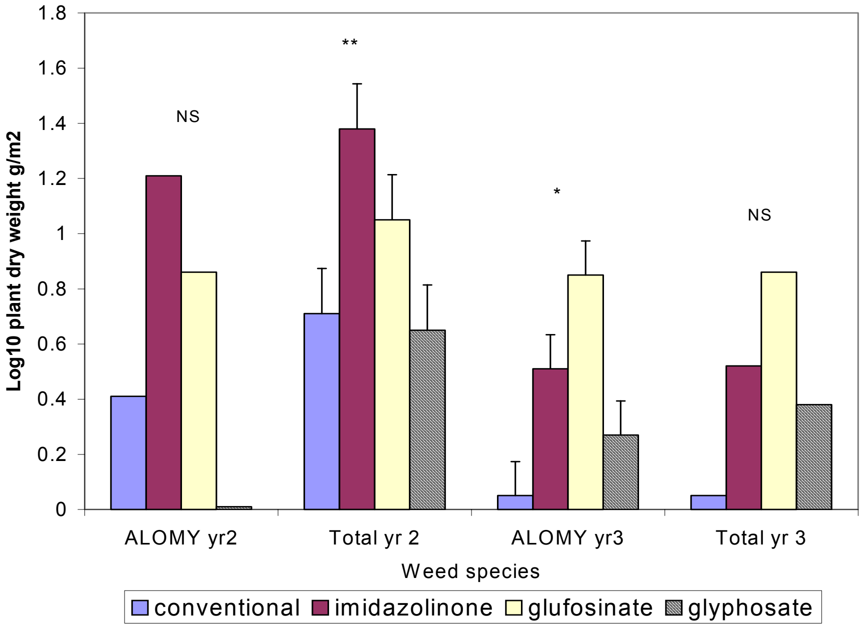


Figure 5.1.3.3. Response of weeds in rotation 1 at NIAB to the herbicides applied in years 2 and 3: biomass assessment in summer of total weeds and *A. myosuroides* (black-grass) (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, vertical bars = 1 x sed)

Year 4 - oilseed rape

Due to the imazamox tolerant rape being withdrawn the treatment was replaced with a second conventional treatment of cyloxydim. The overall mean weed density at the autumn assessment was 325 plants/m^2, the high plant density being due to the presence of *T. aestivum* (wheat volunteers) from the previous crop. The field was only lightly cultivated prior to drilling the rape which also contributed to the high emergence of wheat plants after drilling. The mean weed density excluding *T. aestivum* was only 1 plant/m^2. There were no significant treatment differences at this assessment date.

The spring weed assessment showed that all treatments had successfully controlled the main weed, *T. aestivum* (overall mean 0.5 plants/m^2). The main weed present at this assessment was *A. myosuroides* (overall mean 7 plants/m^2), which had mostly emerged after the initial weed count in the autumn and also after the initial herbicide treatments. The highest densities were recorded in the glyphosate treated plots (Fig. 5.1.3.4) and there were significant differences in total weed numbers.

There were no significant results recorded at the biomass assessment timing. None of the treatments fully controlled all the weeds present, the overall mean weed biomass recorded was 84 g/m^2, the most abundant weed at this assessment was *A. myosuroides.* The highest levels of *A. myosuroides* were recorded in the glufosinate and glyphosate treated plots (Fig. 5.1.3.5) partially due to the poorer crop vigour due to water-logging in several areas of the field. In the case of glyphosate less efficient control was principally due to a missed second application due to poor weather conditions in the autumn. A second glufosinate treatment had been applied but to weeds at a less susceptible advanced growth stage . The lack of statistical significance can be at least partly attributed to the waterlogging.

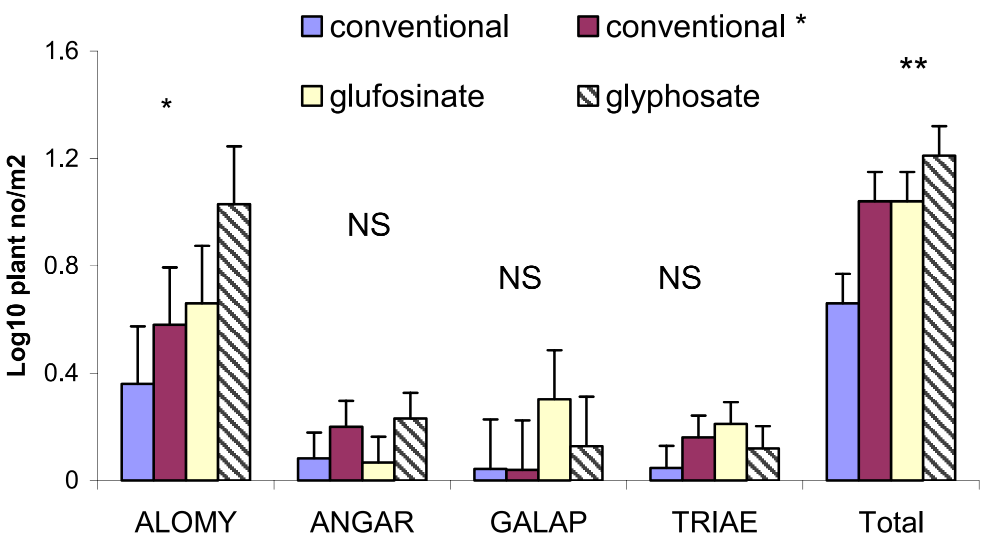


Figure 5.1.3.4. Response of weeds in rotation 1 at NIAB to the herbicides applied in year 4: spring weed density assessment . (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, vertical bars = 1 x sed)

High levels of contaminating weed seed (*A. myosuroides*) were observed in the glyphosate and glufosinate seed samples at harvest. However no significant differences in crop yield were observed between treatments (Fig 6.1.1.1).

Interactions between year 1 and year 4

A low level of significance in year 4 was demonstrated as a result of year 1 treatments for *A. myosuroides,* due to more weeds being recorded in year 1 biomass assessment in the plots treated with imazamox and glufosinate (Table 5.1.3.2). A significant result was also demonstrated as a result of year 1 and year 4 treatments with the total numbers of weeds recorded in the spring. Low levels of significance were also demonstrated as a result of the year 1 and year 4 treatments for *Epilobium tetragonum* although the weed was only present at a low density (<1 plant/m^2) indicating that its biological significance was low. However there were no significant interactions between year 1 and year 4 treatments. Nor were there any significant treatment effects in the year 4 weed biomass data (Table 5.1.3.3.).

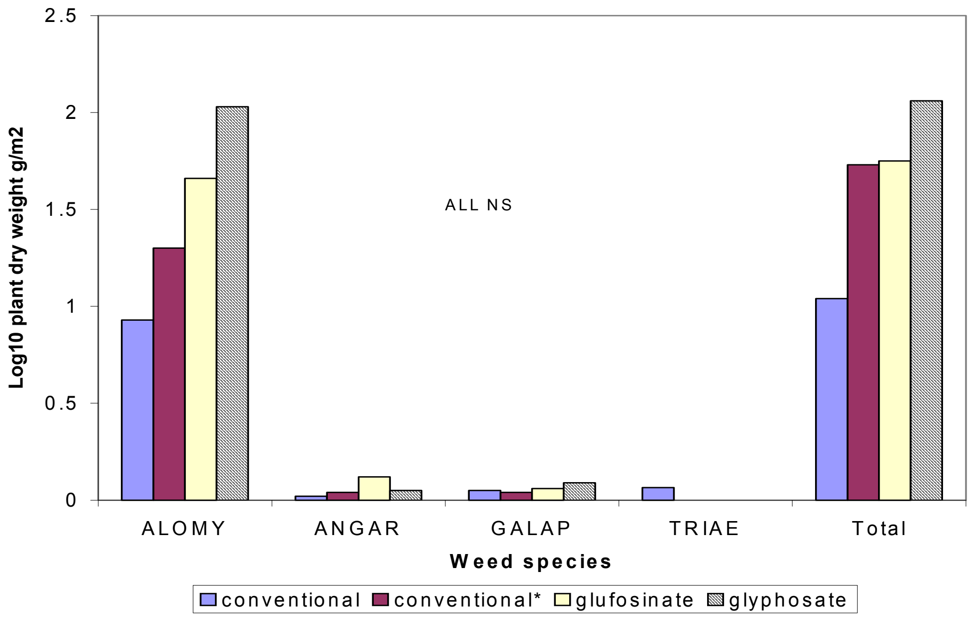


Figure 5.1.3.5. Response of weeds in rotation 1 at NIAB to the herbicides applied in year 4: biomass assessment in summer (All NS - all non-significant)

Table 5.1.3.2 Statistical significance of the year 1 and year 4 treatments on weed density (Log10 plants/m^2) in spring 2002 at NIAB

Weed species	Treat Yr1	Treat Yr4	Interaction
ALOMY	*	NS	NS
ANGAR	NS	NS	NS
GALAP	NS	NS	NS
TRIAE	NS	NS	NS
Total	***	**	NS

Table 5.1.3.3 Statistical significance of the year 1 and year 4 treatments on weed biomass (Log10 g/m^2) in summer 2002 at NIAB

Weed species	Treat Yr1	Treat Yr4	Interaction
ALOMY	NS	NS	NS
ANGAR	NS	NS	NS
GALAP	NS	NS	NS
TRIAE	NS	NS	NS
Total	NS	NS	NS

Conclusions - NIAB

There was some evidence that the levels of weed control in year 1 influenced weed infestations in the following years. In both cereal years (years 2 and 3) *A. myosuroides* was the most dominant weed at the biomass assessment; in year 2 the former imazamox treated plots produced the highest biomass of total weeds (mostly *A. myosuroides),* and in year 3 the former glufosinate treated plots produced the highest biomass of *A. myosuroides*. In both cases the levels could be associated with the less efficient control of the weed by the year 1 treatments. In year 4 the glufosinate treatment again failed to efficiently control *A. myosuroides* after two applications, although it is likely that poor crop vigour due to waterlogging in several areas of the field also contributed to the high biomass results.

In year 1 the glyphosate treatment gave the most efficient weed control followed by the glufosinate treatment. The imazamox and conventional treatments gave equivalent levels of control. In year 4 the conventional, conventional* and glufosinate treatments achieved similar levels of control with the glyphosate treatment performing least well. The change in ranking of treatments from the first year was associated with failure to apply the second treatment of glyphosate, and to the late application of the second treatment of glufosinate, due to difficult soil and weather conditions in the autumn in year 4, resulting in weeds exceeding optimum growth stages for efficient control.

Overall weed biomass was strongly related to the difficulties of controlling *A. myosuroides* in both oilseed rape and wheat. Least weed biomass was present in the two cereal years and most was present in year 4 (Yr1 = 37, Yr2 = 15, Yr3 = 3.4, Yr4 = 54 g/m^2), as a result of the presence of *A. myosuroides.*

5.1.4 Weed Diversity in Rotation 1

5.1.4.1 Rothamsted Rotation 1a /1b

Three different diversity analyses were explored on the Rotation 1 Year 4 data at Rothamsted; SLogN, Log series α and Berger Parker dominance. The basic analyses are presented in Table 5.1.4.1.

Table 5.1.4.1 Effects of the four herbicide treatments applied in Year 4 at Rothamsted on species number (S), assessed by S, SLogN, Log series α and Berger Parker dominance

Analysis	Conventional	Conventional*	Glufosinate	Glyphosate	SED
Species	8.25	9.75	7.58	6.08	0.552
Species + covariate	8.26	9.85	7.62	5.93	0.657
Berger-Parker dominance	0.36	-0.054	0.75	0.55	0.242
Log series α	2.21 (0.57)*	2.70 (0.63)	2.16 (0.56)	1.79 (0.53)	

* figures in brackets are standard errors of values

There was a clearly significant effect of the Year 4 treatments on the number of species present (S) but the addition of the covariate of the plant numbers (N) to these values had virtually no effect on the means. Fewest species were present on the glyphosate treated plots. The log series α analyses also indicated less diversity on the glyphosate plots but the standard errors of the values were very high and the differences were not statistically significant. There was inadequate number of species on the plots fully to exploit the utility of this analysis. The Berger-Parker analyses indicated that the dominant species on the glufosinate plots was of higher importance than on the conventional* plots. It was interesting that the dominant species on the glufosinate plots was *V. arvensis*. In contrast there was no particular dominant species on the glyphosate plots. It was concluded that there was little value in pursuing the analyses of berger-Parker and log series α.

The more detailed GenStat analyses of species number (S) showed that there was a main effect of the treatments applied in year 4 on the species number. This was true in the presence and absence of the covariate for number of individuals counted. No significant effects of the first year of treatments, nor of the covariate, were apparent. The covariate had very little effect on the comparisons between the four treatments.

The greater effect of the year 4 treatments on species number (as modified by the number of plants counted) is clear in Fig 5.1.4.1. The alternative conventional in year 4 (conventional* = cyanazine) resulted in the highest species number, glyphosate resulted in the lowest. There was no strong evidence that there were any interactions with the treatments in year 1, though most species arose in the conventional* plots previously treated with the conventional herbicide and the imidazolinone treatment. The latter tended to give the poorest weed control in year 1 (Section 5.1.1).

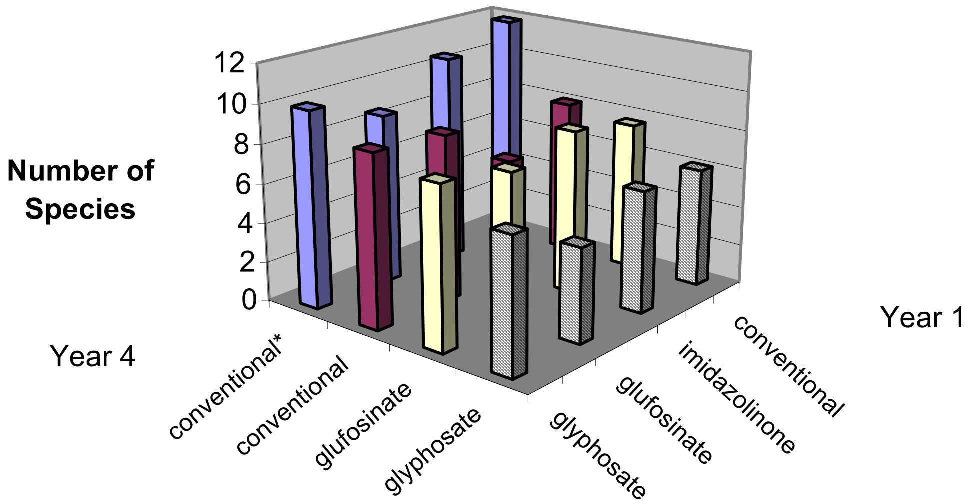


Fig 5.1.4.1 Response of weed species number at Rothamsted to four treatments applied in year 1 and year 4 to oilseed rape in a rape, wheat, wheat, rape rotation. (sed = 1.56)

5.1.4.2 Scottish Agricultural College Rotation 1a/1b

Like Rothamsted, the main effect on species number was from the treatments applied in year 4. But unlike Rothamsted, there was an effect from the year 1 treatments and the inclusion of the covariate based on the number of individual plants counted (Log N) also had a significant effect. Overall, there were not many species present, as the maximum mean value was only 7.5 species. For the reasons mentioned in the introduction this may be an under-estimate and this may have been compounded, as for some species (e.g. *Matricaria* species) the assessors simply recorded 'mayweed'. The inclusion of the covariate (total plant number) tended to up rate the species number for glyphosate in year 4.

In year 1 most species tended to be present on the conventional and glyphosate plots and in year 4 least on the glyphosate plots. The significance of the year 4 differences (p=0.002) was greater than the year 1's (p=0.014). Overall, most species were found on plots receiving glyphosate in year 1 and glufosinate in year 4, whilst fewest species were assessed on those receiving glufosinate in year 1 and glyphosate in year 4 (Fig. 5.1.4.2). This tends to indicate no major differences between treatments and certainly no cumulative effects, as is confirmed by the absence of an interaction between the two years.

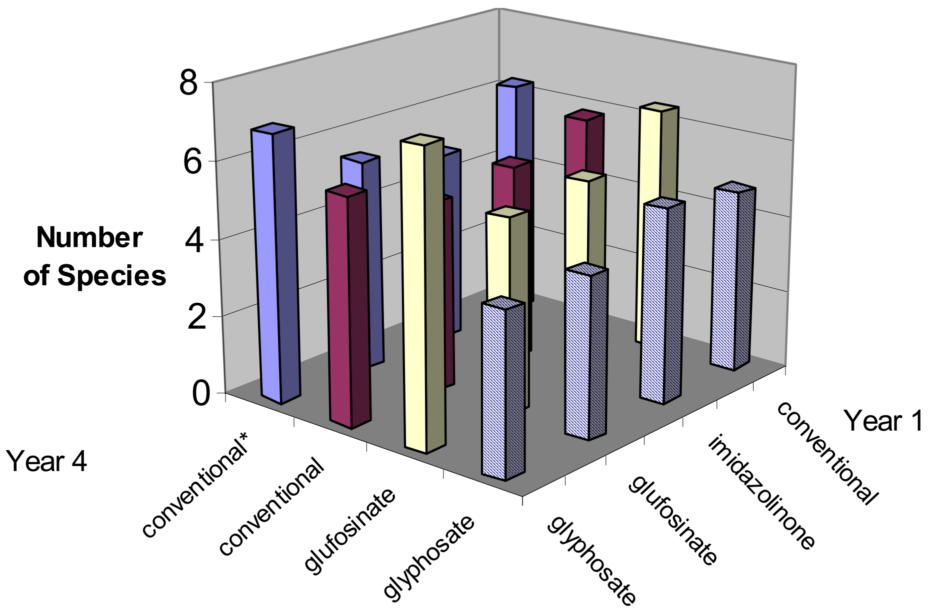


Fig. 5.1.4.2 Response of weed species number at SAC to four treatments applied in year 1 and year 4 to oilseed rape in a rape, wheat, wheat, rape rotation. (sed = 1.07)

5.1.4.3 NIAB - Rotation 1

Weed species number were low on this experiment at NIAB (Section 5.1.3). Mean species number/plot did not exceed 7 species. There were no significant effects of the year 1 treatments but there were effects of those applied in year 4. There were no interactions and the use of the covariate did not improve the analyses. Fewer species were present on the plots treated with the alternative conventional herbicide (conventional*) and those treated with glufosinate, in year 4 (Fig 5.1.4.3).

5.1.4.4 Conclusions on weed species diversity in Rotation 1

Although the potential of several diversity indices (S, SLogN, Log series α, Berger-Parker) were investigated it was concluded that the most informative was the use of the simple assessment of species number (S and SLogN). At two of the three sites the inclusion of the covariate of number of plants counted (N) had no significant effect and at the third site (SAC) it had a relatively small impact. This is perhaps not surprising as the variation in weed numbers within a field is unlikely to be huge, bearing in mind that the analysis uses LogN as the covariate. Weed densities often vary by a factor of 10 or sometimes 100 but in the context of the 'standard' use of this analysis in natural ecosystems where numbers of individuals can easily vary by more than a factor of 1000, this variation is relatively small. Bigger differences could have been expected in comparisons including a wide range of sites. Overall species numbers present on the three sites were relatively low (maximum 12 species/treatment). This reflects the limited range of species adapted for the disturbed ecosystem of arable fields and secondly the fact that the species are the survivors of herbicide treatments. This limited range of species in intensively farmed arable fields has previously been shown in the analyses of the results of the 'Boxworth project', which compared high and lower intensity crop management over 4 years on groups of fields at the ADAS Boxworth farm (Marshall, 1992; Marshall & Arnold, 1994).

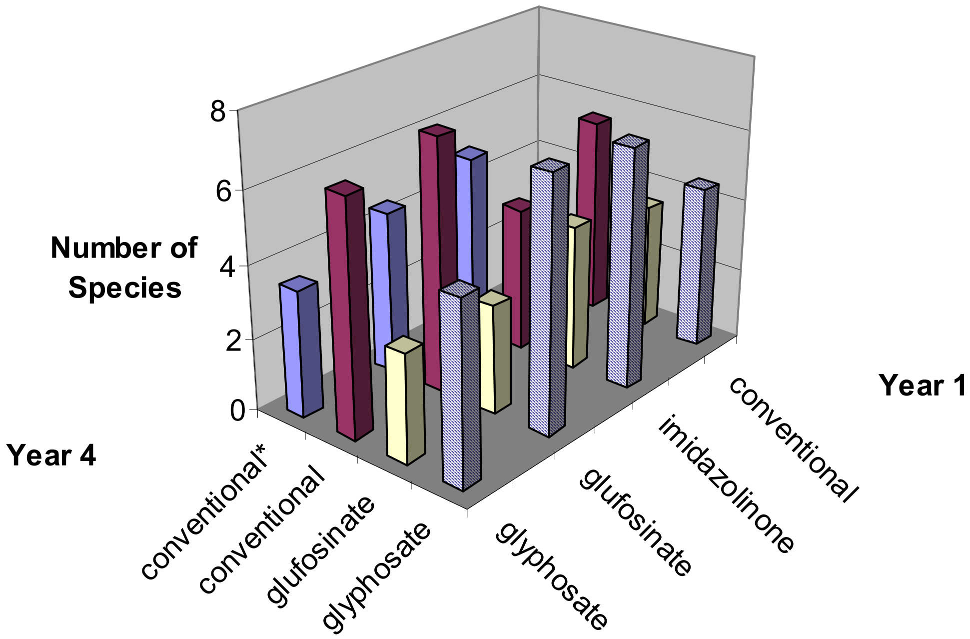


Fig. 5.1.4.3 Response of weed species number at NIAB to four treatments applied in year 1 and year 4 to oilseed rape in a rape, wheat, wheat, rape rotation. (sed =2.22)

The main significant effects were attributed to the treatments applied in year 4. Only at SAC was there a significant effect from the year 1 treatment. This is not surprising as the analysis will have been driven primarily by the treatments applied earlier in the season that the assessments were done (i.e. year 4). There were no clear trends in the data as to which of the year 4 treatments resulted in the most or least species. At two of the three sites fewest species followed use of glyphosate but at the third this was not the case, as fewest species followed the conventional* and glufosinate treatments. Indeed at SAC the treatments causing the maximum and minimum number of species were completely opposed in years 1 and 4.

This analysis was not particularly well suited to the data sets generated in BRIGHT as the range of species numbers within fields, resulting from the treatments was relatively small. The analysis is far better suited to comparisons that involve similar treatments applied over a large number of sites, as has been done in the Farm Scale Evaluation of GM crops (Firbank *et al*., 2003).

5.1.5 Changes in the weed seedbank in Rotation 1

5.1.5.1 Introduction

One of the postulated impacts of the planting of herbicide tolerant crops, and their perceived more effective weed control, would be a decline in the levels of weeds in arable fields, with possible impacts on diversity in arable ecosystems. If herbicide tolerant crops were more effective they would reduce the levels of seed return by weeds and so the soil seedbank would decline after planting of these crops. This might take some years to manifest itself but detailed studies of the seedbank might reveal the initiation of trends in the shorter term. In the BRIGHT project rotations 1, 2 and 3, each site was planted with two herbicide tolerant crops, in comparison to conventional ones, over the four years of the project. Thus it is possible that the different levels of weed control achieved when the comparative crops were grown could be manifested in changes in the seedbank. Seedbanks were intensively sampled at the onset of the project (autumn 1998) and at the end of the project (summer/autumn 2002), after any weeds surviving the final crop had shed seeds. Details are given in Section 4: Materials and Methods.

5.1.5.2 Rothamsted

Year 1

At Rothamsted a limited range of weeds dominated the seedbank, though a total of 18 species were identified. The main species were *V. arvensis* (VIOAR), several *Veronica* species (VER spp.) (mainly *V. persica* but also *V. arvensis*), *S. media* (STEME), *P. rhoeas* (PAPRH), *C. album* (CHEAL) and *A. cynapium* (AETCY) (Fig 5.1.5.1).

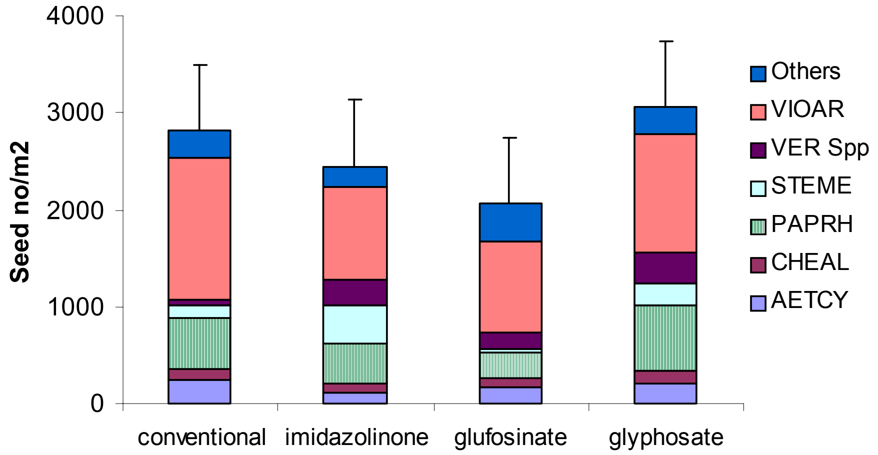
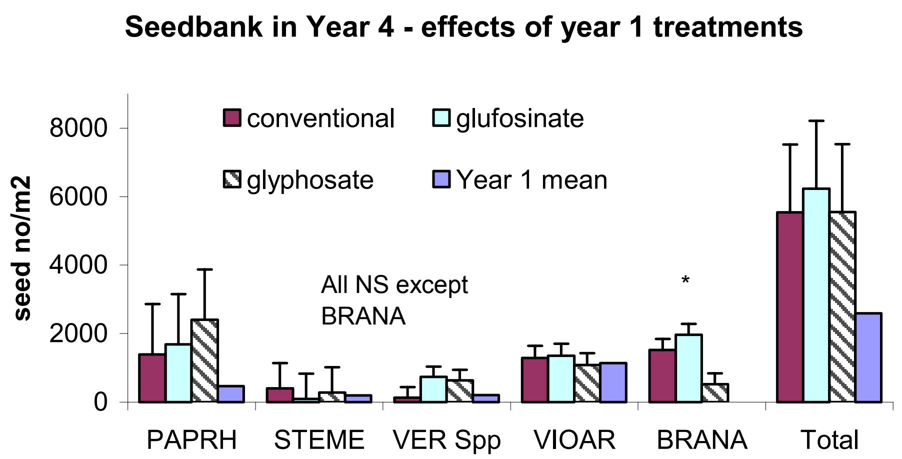


Fig 5.1.5.1. Seed numbers/m^2 of the main weeds in the seedbank in autumn 1998, prior to the application of the treatments. Vertical bars are SEDs of the total weed numbers

Although weed seed numbers varied across the plots, prior to the treatments affecting the weeds, these treatment differences were not high, except perhaps for *S. media*. None was significant statistically, but the data were quite variable. Variability in numbers is a feature of seedbank studies because of the heterogeneity of the distribution of seeds in the soil and because of the relatively small samples that can be processed.

The overall mean was 2595 seeds/m^2. Assuming a uniform distribution of seeds in the soil (following annual ploughing on the site over a number of years) the top 1cm of soil from the 25 cm soil cores would contain c. 100 seeds/m^2, a figure similar to that presented in the review by Marshall *et al* (2003) on weeds and biodiversity. This is lower than was the case in the earlier part of the last century.



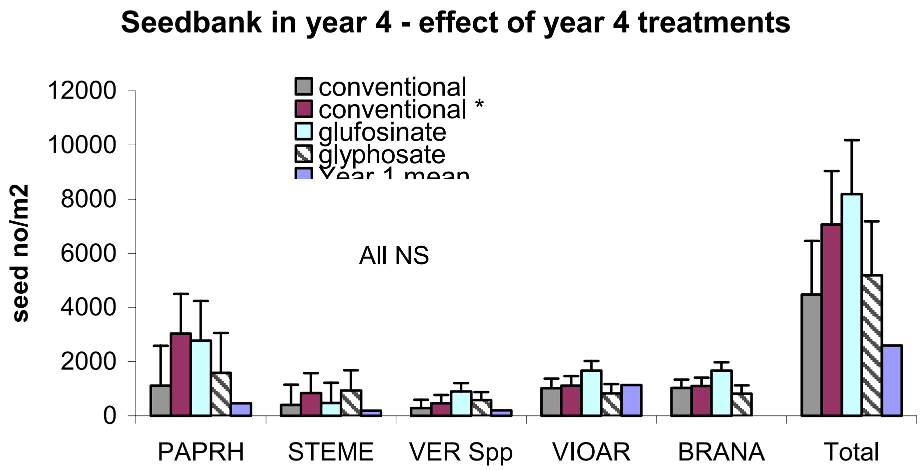


Fig 5.1.5.2 Seedbank at Rothamsted at the end of year 4, following treatment in year 1 and year 4, mean density at the start of year 1 given for comparison. (NS = no significant effect of treatment; stars = significance *p<0.05, Vertical bars are SEDs)

Year 4

The seedbank sampled at the end of the project would have been influenced by the treatments applied in year 1 and year 4, when four types of rape were compared. The year 1 imidazolinone data was omitted from this analysis because it was not fully replicated and consequently impacted on the identification of interactions between year 1 and year 4. When the Year 4 data compares the effects of the Year 1 treatments the means combine the impacts of the Year 4 treatments. Similarly, the comparison of the Year 4 treatments amalgamates the effects of all the Year 1 treatments. These analyses of the main effects of the year of treatment are successful if there is no interaction between the Year 1 and Year 4 treatments. There were no significant interactions.

Figure 5.1.5.2, presenting the untransformed data, shows that the variability in the data is high and as a consequence there are no significant differences between treatments. Similarly the GenStat analyses failed to identify significant interactions between year 1 and year 4 treatments. Total weed numbers when Log10 transformed showed a significant effect of the year 4 treatments with higher weed numbers on the plots treated with glufosinate and with the alternative conventional (conventional*). Overall seed numbers had increased from 2595 seeds/m^2 in year 1 to 5773 seeds/m^2. This was due to the addition of volunteer rape seeds to the seedbank from the two rape crops (max c. 2000 seeds/m^2) and to poor control of *P. rhoeas* and *S. media* during the four years of the experiment. There was still a 70% increase in the seed bank even in the absence of the contribution from the oilseed rape. The earlier weed control data indicates that this increase arose in the rape years and not in the years when wheat was grown.

5.1.5.3 Scottish Agricultural College

Year 1

The seedbank at SAC at the start of the experiment was dominated by *S. media* (STEME) and *P. annua* (POAAN), with some *M. arvensis* and *V. arvensis* (Fig 5.1.5.3). There were no major differences between the treatments (prior to their application) and no statistically significant effects were detected. Interestingly *P. annua* was far commoner as a seedling in year 1 than *S. media*, despite the latter's higher seedbank. Overall there was a mean of 8239 seeds/m^2.

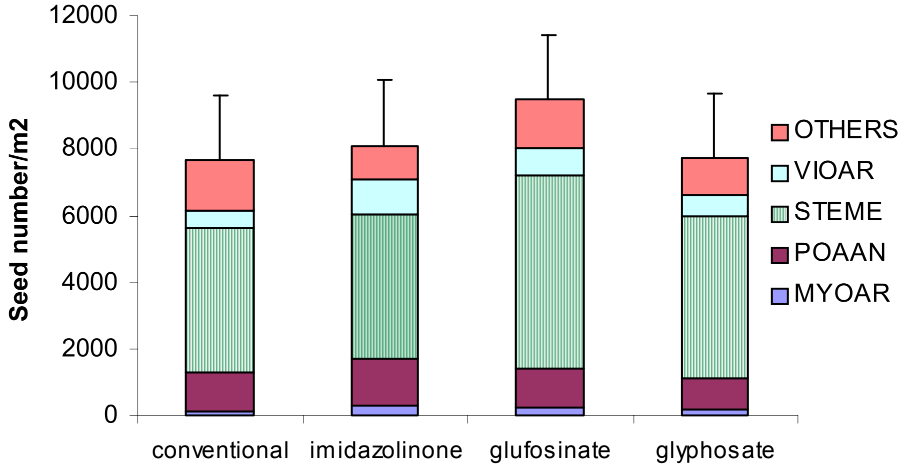
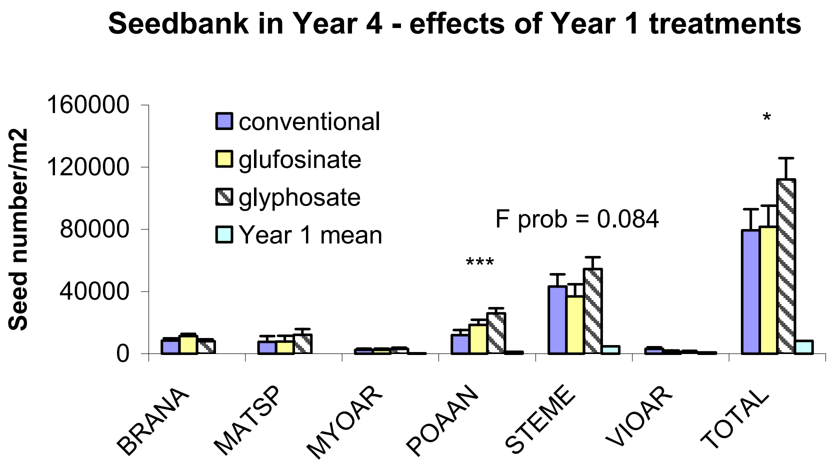


Figure 5.1.5.3 SAC seed number/m^2 of the main weeds in the seedbank in autumn 1998, prior to the application of the treatments. Vertical bars are the SEDs of the total weed numbers.

Year 4

At the end of the experiment the seedbank could have been influenced by the treatments used in year 1 and those used in year 4 and by an interaction between the two. The overall seedbank could also have been affected by seed production during the cereal years (Years 2 & 3). At the other sites weed control in the cereals was high but this was not the situation at SAC where, especially in year 3, weed numbers during spring and summer were appreciable (Section 5.1.2). The factorial analyses of both the raw data and the log transformed data showed no significant interactions, though there were some main effects. As at Rothamsted the variability in the data may have masked some treatment effects. The clearest effect was the increase in all species in year 4, compared to 1998. The overall mean was 89,323 seeds/m^2, a ten fold increase over year 1. Oilseed rape was only approximately 10% of this seed bank. The overall increase in seed numbers of the species over year 1 (Fig. 5.1.5.4.) can be linked particularly to the weed infestations in year 3 where the high biomass on all plots would have given high levels of seed production. There is no clear evidence that any treatment or combination of treatments in the years when oilseed rape was grown, caused either greater or smaller increases.



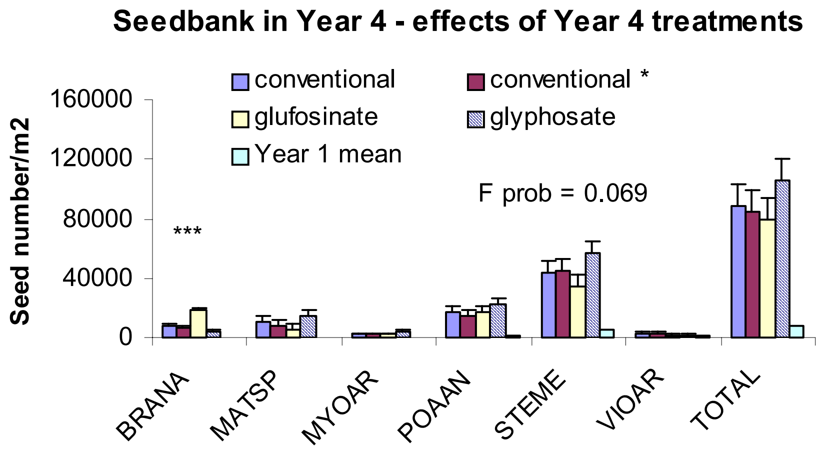


Figure 5.1.5.4. SAC seedbank at the end of year 4, following treatment in year 1 and year 4; mean density at the start of year 1 given for comparison. Vertical bars are SEDs.

S. media dominated the seedbank in year 4, while oilseed rape and *Matricaria* spp. featured as new significant parts of the seedbank. Some statistically significant effects of treatments were detected. As a result of the year 1 treatment there was more *P. annua* on the glyphosate treated plots and the same treatment gave an indication of higher levels of *S. media*. There was some indication that more seeds overall were present on the plots treated with glyphosate in year 1. A similar higher level after glyphosate was noted for *S. media*, as a result of the year 4 treatments. There were also significantly more oilseed rape seeds on the plots treated with glufosinate. This does not seem to be linked to higher yields or higher post-harvest seed losses from this cultivar in 2002 (Section 6.1).

5.1.5.4 NIAB

Year 1

There were only a limited number of species at NIAB at the start of the BRIGHT programme. The commonest were *Anagallis arvensis* (ANGAR), *Chenopodium album* (CHEAL) and *Kickxia spuria* (KICSP). Total weed seed numbers were only 3051 /m^2 (Fig 5.1.5.5). Fifteen species were present including a very low level of volunteer oilseed rape, but only the three mentioned above exceeded 150 seeds/m^2. Annual grasses such as *P. annua* and *A. myosuroides* were present but only at densities below 100 seeds/m^2. The data were rather variable, as can be seen from the size of the standard errors. *A. arvensis* appeared more frequent on the plots intended for the glufosinate and conventional treatments and *C. album* on the glyphosate plots. The latter was statistically significantly higher (Significance = **) than for the other treatments.

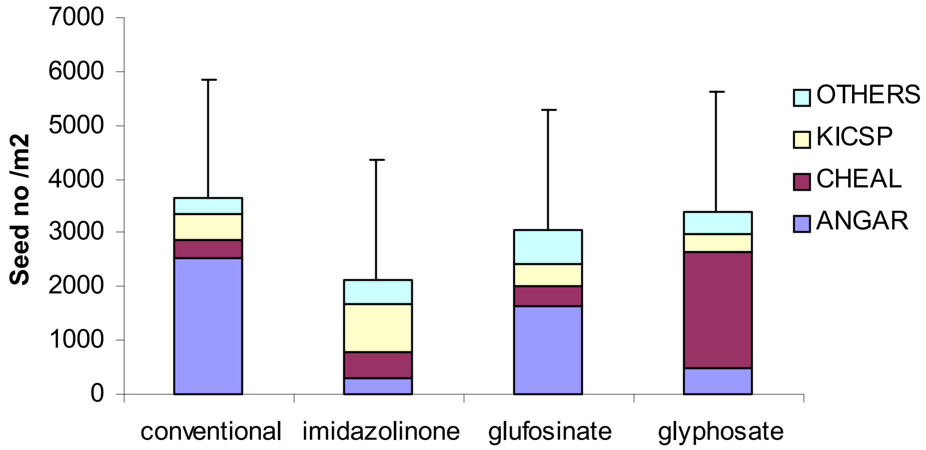
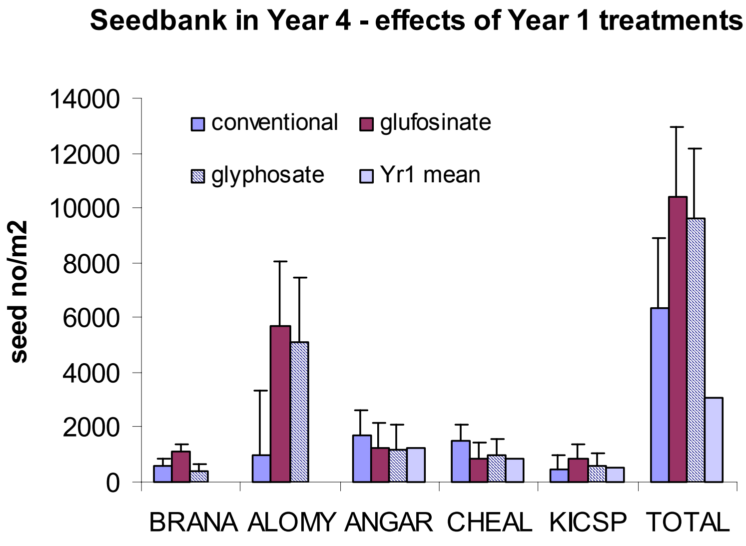


Figure 5.1.5.5 Seed number/m^2 of the main weeds at NIAB in the seedbank in autumn 1998, prior to the application of the treatments. Vertical bars are the SEDs of the total weed numbers.

Year 4

After four years and two selective treatments of herbicides in the oilseed rape, the overall level of weeds had increased to 8774 seeds/m^2. This was primarily due to a massive increase in *A. myosuroides* (overall mean = 3932 seeds/m^2) and of the presence of substantial numbers of seeds of volunteer rape (mean = 703 seeds/m^2) (Fig. 5.1.5.6). The data were still very variable and the untransformed data showed no significant effects from either the year 1 or the year 4 treatments or of any interactions. Neither did the log10 transformed data except for *A. myosuroides* which showed some significance. *C. album* and *K. spuria* were still present though virtually no plants had been seen on the plots over the four years. Some volunteer rape was also present in year 4.



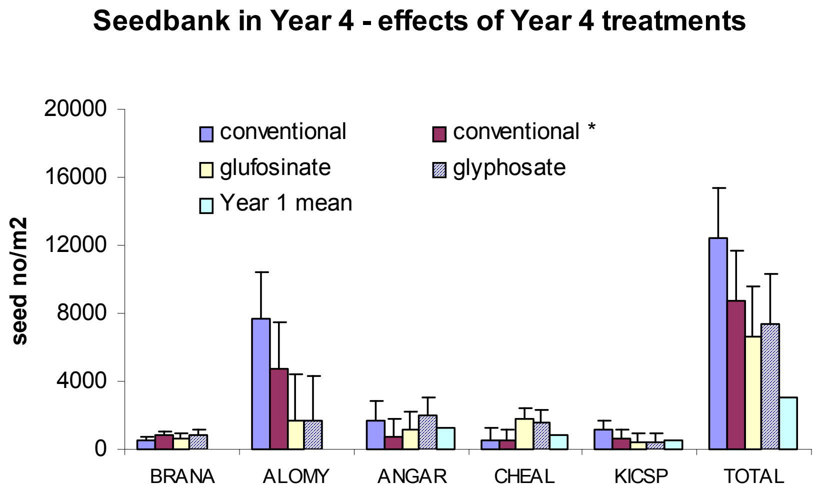


Figure 5.1.5.6 Seedbank at the end of year 4 at NIAB, following treatments in year 1 and year 4; mean density at the start of year 1 given for comparison. Vertical bars are SEDs. All treatment differences non-significant.

When assessing the overall effects of the treatments on *A. myosuroides* there was a significant effect of the year 1 treatments (p= <0.01) and nearly a significant effect of the year 4 treatments (p= 0.08) (Fig. 5.1.5.7). Fewest seeds were found on the plots treated with the conventional herbicides in year 1 which agreed with the plant assessment in year 1 (Section 5.1.3). This effect appears to have carried through into year 4. Most seeds were found on the conventional and conventional* treated plots in year 4, which had received glyphosate and glufosinate in year 1. Most biomass of this weed appeared to be present on plots treated with these two treatments in year 4, though the differences between the treatments were not statistically significant (Section 5.1.3).

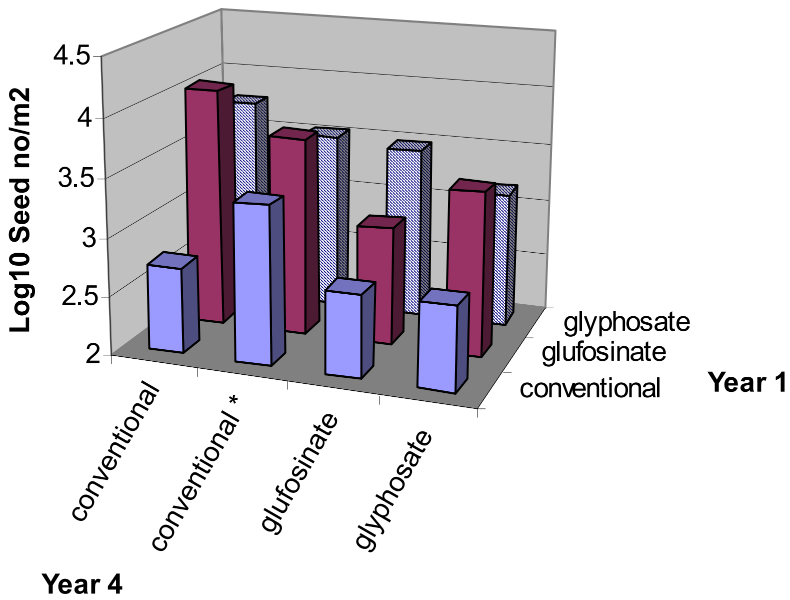


Figure 5.1.5.7 The effect of the year 1 and year 4 treatments at NIAB on the number of *A. myosuroides* seeds/m^2 in year 4. (Log 10 transformed data; SED = 0.365)

5.1.6 General conclusions from Rotation 1

Weed control

Glyphosate treatments gave the highest levels of weed control at Rothamsted in years 1 and 4, and at NIAB in year 1. However the efficacy of glyphosate was less at NIAB in year 4 and at SAC. Glufosinate gave the best control of weeds at SAC. The changes in efficacy at NIAB appeared to be due to problems with applying the herbicide at the correct timing and rain events around the time of application in year 4. It should be noted that although significant effects were recorded at all three sites, the variability in the information at SAC where there were four replicates was not much less than that at NIAB, where there were only two. Treatment differences were more easily detected at Rothamsted, the second site with four replications.

Weed Species Diversity

At SAC the highest number of species was found on plots receiving glyphosate in year 1 and glufosinate in year 4, whilst fewest species were assessed on those receiving glufosinate in year 1 and glyphosate in year 4.

At Rothamsted the alternative conventional in year 4 (conventional* = cyanazine) resulted in the highest species number, glyphosate resulted in the lowest. There was no strong evidence that there were any interactions with the treatments in year 1, though most species arose in the conventional* plots previously treated with the conventional herbicide and the imidazolinone treatment.

At NIAB weed species numbers were low and variable so that no treatment effects were discernable. This tends to indicate no major differences between treatments and certainly no cumulative effects, as is confirmed by the absence of an interaction between the two years.

Seed banks

The largest increases in weed seed numbers were in the glyphosate treated plots at SAC, the glufosinate treated plots in year 4 at Rothamsted and the conventional treated plots in year 4 at NIAB. Lowest seed counts were in plots treated with conventional herbicides in years 1 and 4 at SAC and year 1 at NIAB. These results partially fit with the results of the weed control and the weed biomass data collected at these sites but correlations are poor due to high variability. At Rothamsted weed biomass and hence seed return was much lower in the cereal years than when oilseed rape was grown. This was not the case at SAC where the absence of herbicide treatment in barley in year 3 would have resulted in very high seed returns.

Overall view

Overall these results show that glufosinate and glyphosate can give as good or sometimes better weed control in oilseed rape than conventional herbicides but that the efficacy depends very much on local conditions at the time of treatment. The HT treatments appear to have larger windows of opportunity for timing of application in relation to weed and crop growth stage. However they are also sensitive to weather conditions and weeds may escape treatment in certain seasons due to soil moisture and temperature conditions prevailing during the autumn. Treatments had no clear effects on species diversity. Similarly impacts on the seed bank seemed to reflect the variable performance of the products at the different sites and in different years.

Thus, from Rotation 1 it is difficult to conclude that any one treatment was always more effective, had more impact on botanical diversity or was likely to have more impact on seed banks.

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5.2 Rotation 2 (sugar beet – cereals – cereals – sugar beet)

In this rotation two herbicide tolerant and a conventional variety of sugar beet were grown in the first and final years with winter cereal crops grown in the two intervening years. Weed assessments were made prior to, and after, herbicide applications and weed biomass was recorded at the end of the growing season prior to harvest.

5.2.1 Broom's Barn

The main weeds to occur on Rotation 2 at Broom's Barn were *Chenopodium album* (CHEAL – fat hen), *Fallopia convolvulus* (FALCO - black bindweed), *Poa annua* (POAAN – annual meadow-grass), *Stellaria media* (STEME – common chickweed), *Veronica persica* (VERPE – common field speedwell) and *Viola arvensis* (VIOAR – field pansy).

Year 1 - Sugar beet

Three herbicide treatments were applied to the sugar beet in the spring of 1999. Two populations of weeds were present, large *S. media*, *V. persica*, *Avena sativa*, *Tripleurospermum inodorum* and *V. arvensis* which had survived cultivation and drilling, and newly emerged cotyledon sized plants of *C. album*, *F. convolvulus*, *S. media*, *V. arvensis* and *Lamium purpureum* (see Table 5.2.1.1). The most common weed was *C. album* accounting for more than half of the weeds present. Significant differences were seen in the pre-treatment counts for *C. album* and approaches significance for total weeds (p=0.073); *C. album* counts were greatest on the glufosinate plots and smallest on the conventional plots (Fig 5.2.1.1). This species is largely responsible for the effect seen on the total weed counts.

Table 5.2.1.1 Density of the major weeds present on Rotation 2, prior to treatment in spring 1999

Species	Mean weed density in spring 1999 (plants/m^2)*
Avena sativa	0.3
Chenopodium album	7.9
Fallopia convolvulus	0.6
Poa annua	0.1
Stellaria media	0.7
Veronica persica	0.3
Viola arvensis	0.3
Total weeds	10.7

* combined numbers from two assessments of weed emergence (see text)

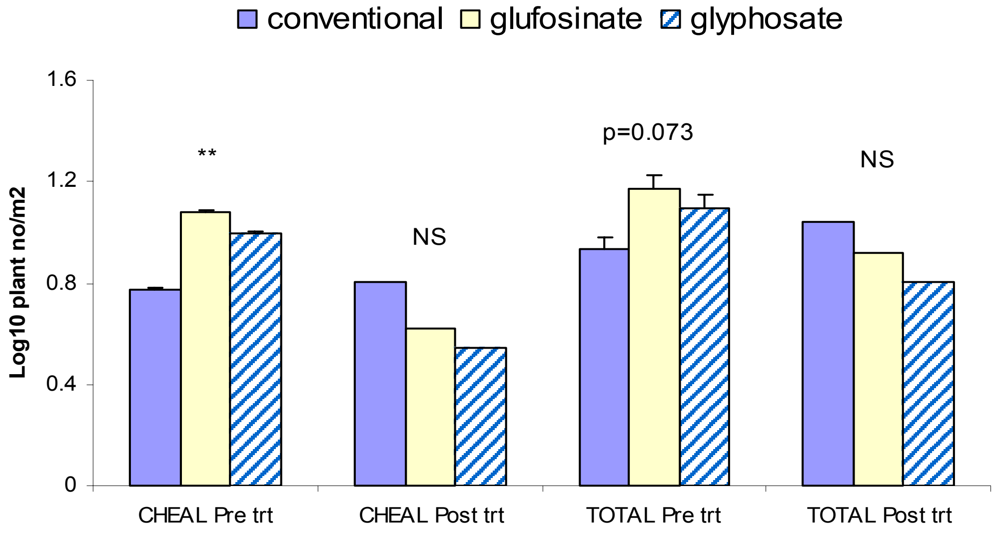


Figure 5.2.1.1. Broom's Barn Rotation 2 : Densities of *C. album* and total weeds before and after herbicide treatment in May-June in year 1. (NS = no significant effect of treatment: stars = significance, ** p<0.01,)

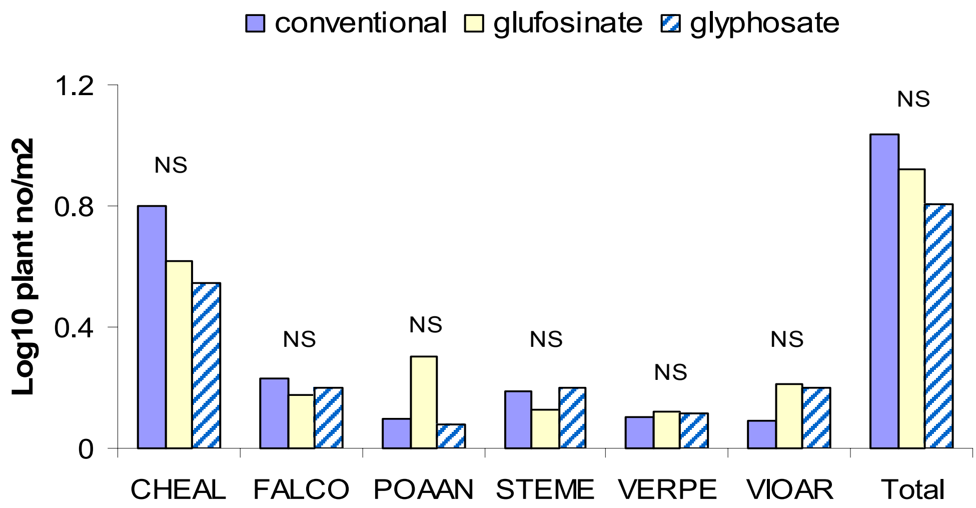


Figure 5.2.1.2. Broom's Barn Rotation 2 : Response of weeds in year 1, to the herbicide treatments applied in May-June in year 1: post herbicide assessment of weed density (NS = no significant effect of treatment)

After the herbicide applications, pre-treatment differences in weed numbers were no longer significant (Fig. 5.2.1.2). *C. album* remained the most numerous weed with a mean of 3.5 plants/m^2 from a total mean of 7.3 weeds/m^2. It was considered necessary to apply a second later application of glufosinate and only these plots were treated on 6 August. A subsequent count on 16 August found significant treatment differences only for *V. arvensis*, but it was present at low levels (mean = 0.3 plants/m^2). The total number of weeds (mean = 28 weeds/m^2) did not differ between treatments. The weed numbers had increased due to new germination of several species; *V. persica* and *S. media*.

Biomass assessments later in the year did not show any significant difference for any species between treatments, although the trend was for greater biomass on conventional plots than on glufosinate plots and least on glyphosate plots (Fig 5.2.1.3) (Plate 5.2.1.1). Mean biomass for all treatments was 23.5 g/m^2 and the species with the greatest biomass were *C. album* (13.1 g/m^2) and *F. convolvulus* (4.0 g /m^2).

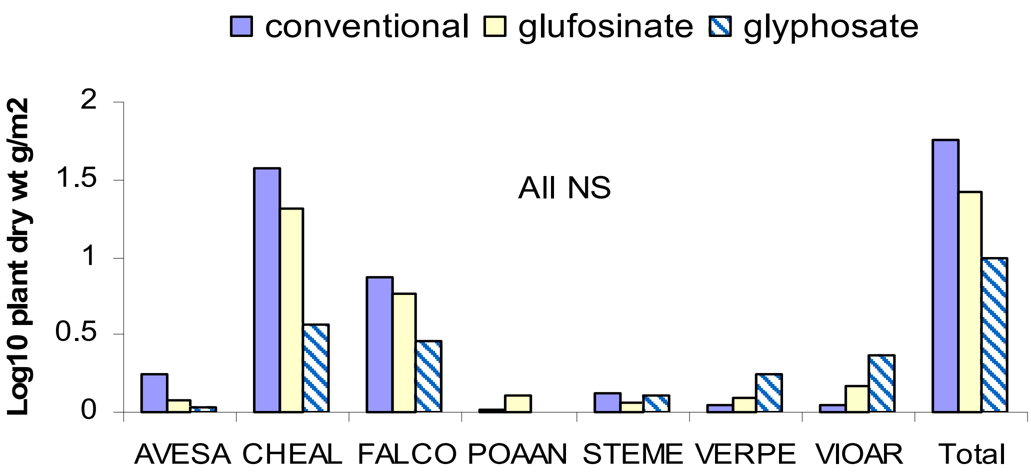


Figure 5.2.1.3 Broom's Barn rotation 2: biomass assessment in late summer year 1 following treatments in year 1 (NS = no significant effect of treatment)

Year 2 - Winter barley

In year 2 the plots were drilled with winter barley. Weed numbers in the autumn were generally higher than had been seen in the spring in year 1 with a mean total density across the treatments of 24.0 plants/m^2 (Plate 5.2.1.2. The most common species were *P. annua*, *S. media*, *Veronica* spp., *C. album*, and *Capsella bursa-pastoris*. No significant differences were seen between treatments. Only effects occurring in species present at densities of >1/m^2 or biomass of more than 0.1 g dm/m^2 are presented. The plots were treated uniformly, all receiving a standard weed control programme (Table 10.2.4), which included the use of a sulfonylurea herbicide as a standard treatment against GM beet volunteers.

In the following spring the mean density had dropped to 1.8 plants/m^2 and the main surviving weed species are shown in Fig. 5.2.1.4. The only significant effects were on *Matricaria* spp. which was present at very low density (0.2 plants/m^2). Weed biomass in summer was very low (mean 0.45 g/m^2) and the only significant differences were in *V. arvensis* and *Sonchus* spp. which had very low biomass (Fig 5.2.1.5).

Plate 5.2.1.1. Broom's Barn, Rotation 2 : Sugar beet treated with glyphosate showing effective weed control in a plot and large amounts of *C. album* in adjacent untreated areas in late summer.

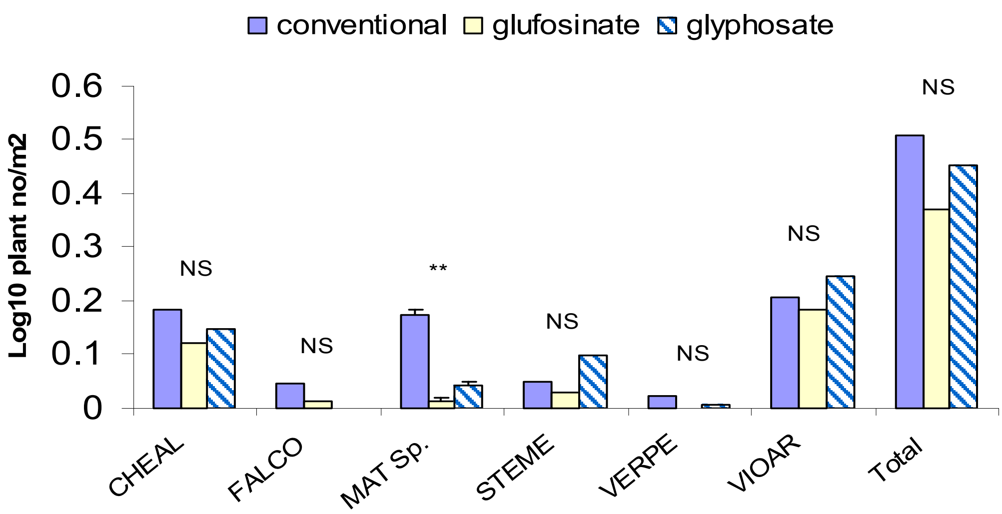


Figure 5.2.1.4 Broom's Barn rotation 2: Response of weeds in year 2, to the herbicide treatments in applied in year 1: spring assessment of weed density (NS = no significant effect of treatment: stars = significance ** p<0.01)

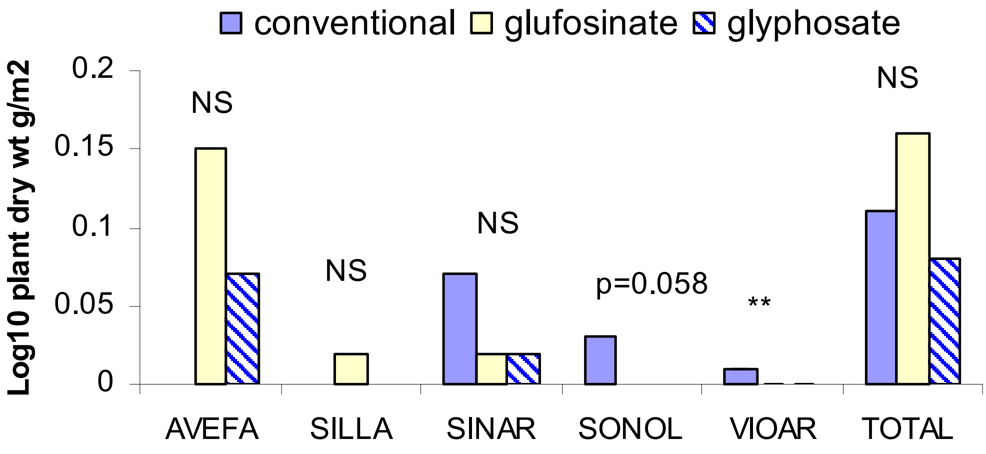


Figure 5.2.1.5 Broom's Barn Rotation 2 : biomass assessment in summer year 2 following treatments in year 1 (NS = no significant effect of treatment: stars = significance ** p<0.01)

Year 3 Winter barley

Autumn weed counts were lower than in year 2 with a mean of 11.9 plants/m^2. The dominant weeds were *V. persica*, *Rumex obtusifolius*, *P. annua* and *S. media*. The cereal herbicide programmes were effective and in spring the weed densities had dropped to 5.2 plants/m^2. There were no significant effects of year 1 treatment on either the spring weed count or the biomass (Fig. 5.2.1.6). There was a treatment effect on *C. album* (p=0.078) but numbers were very low. Biomass was also low (1.0 g D.M. /m^2) though slightly higher than in year 2 (Fig. 5.2.1.7).

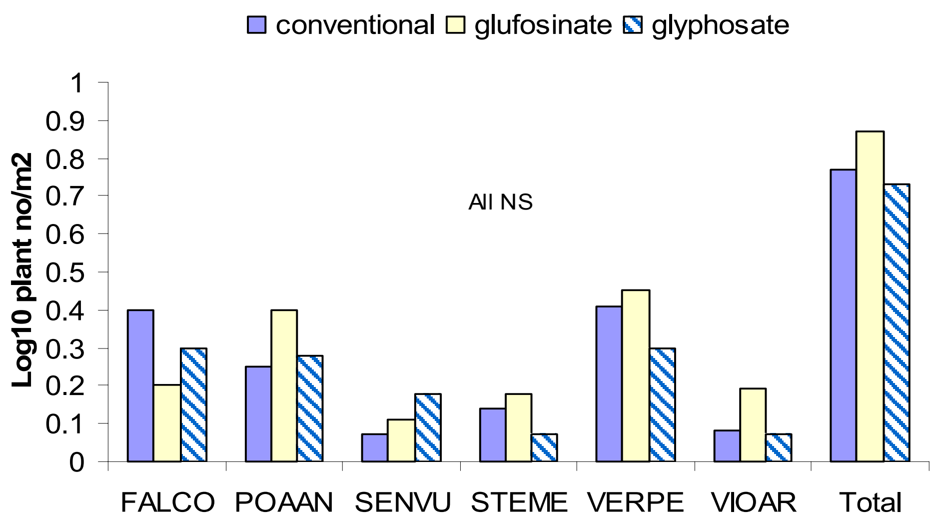


Figure 5.2.1.6. Broom's Barn Rotation 2 : Response of weeds in year 3, to the herbicide treatments in applied in year 1: spring assessment of weed density (NS = no significant effect of treatment)

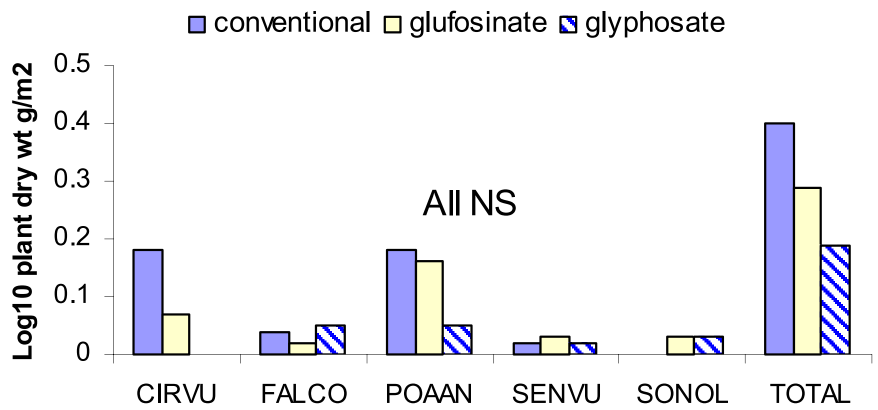


Figure 5.2.1.7. Broom's Barn Rotation 2 : biomass assessment in summer year 3 following treatments in year 1 (NS = no significant effect of treatment)

Year 4 - Sugar beet

In this year it was not possible to count weeds pre-treatment because the conventional plots received a pre-emergence herbicide. Counts were taken post-conventional sprays and post all herbicide sprays. A second application of glufosinate was necessary on 12th July and a later count on all plots was made on 23rd July. The final weed counts taken on these plots indicated significant year 4 treatment effects for seven species (Fig. 5.2.1.8) however there was no consistent effect of treatment. Of the species at densities > $1/m^2$, *F.*

convolvulus (*P. convolvulus*) density was greater on glyphosate plots and *V. arvensis* density was greater on glufosinate plots. The total weed densities for all species were not significantly different between treatments.

Year 4 treatments were randomised within the plots from year 1 and effects in year 4 could be the result of these treatments. The factorial analysis (Table 5.2.1.2) showed no effects of year 1 treatments and no significant interactions between years. The weed counts on GM plots (glufosinate 60.5, glyphosate 42.4 plants/m^2) taken post application of conventional herbicides but prior to that of GM treatments give some indication of the weed densities which might have been seen on the conventional plots had they not been treated pre-emergence. Weed control on the GM plots was equally as good as the conventional and the final weed densities averaged across treatments was 7.9 plants/m^2.

Table 5.2.1.2 Statistical significance of the year 1 and year 4 treatments in Rotation 2 on weed density (Log10 plants/m^2) post GM treatment at Broom's Barn

Weed	TreatsYr1	TreatsYr4	Interaction	Mean weed density (plants/m^2)
CAPBP	NS	**	NS	0.1
CHEAL	NS	*	NS	0.1
CIRAR	NS	**	NS	0.2
FALCO	NS	**	NS	1.5
POAAN	NS	*	NS	0.6
SENVU	NS	***	NS	0.2
VERPE	NS	**	NS	0.2
VIOAR	NS	p=0.092	NS	1.4
TOTAL	NS	NS	NS	7.9

(NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

Weed biomass data was analysed in the same way. Weed biomass across the treatments in year 4 averaged 12.9 g D.M./m^2. Biomass was apparently greatest on the conventional, and lowest on the glyphosate plots (Fig.5.2.1.9). This is in part due to poorer crop competition and lower crop populations on conventional plots, resulting from animal and bird grazing early in the life of the experiment when the conventional plots were weed-free and the crop plants were the only vegetation present.

The $\log_{10}$ factorial analysis comparing year 1 and year 4 treatments showed significant effects only on *C. album* and approached significance for *F. convolvulus* (p=0.067) and total weeds (p=0.051) for year 4 only. No year 1 effects or interaction effects were seen. The greatest biomass was seen in *C. album* (conventional), *F. convolvulus* (on glufosinate and glyphosate) and *V. arvensis* (on conventional and glufosinate) although the results for *F. convolvulus* and *V. arvensis* were not significant.

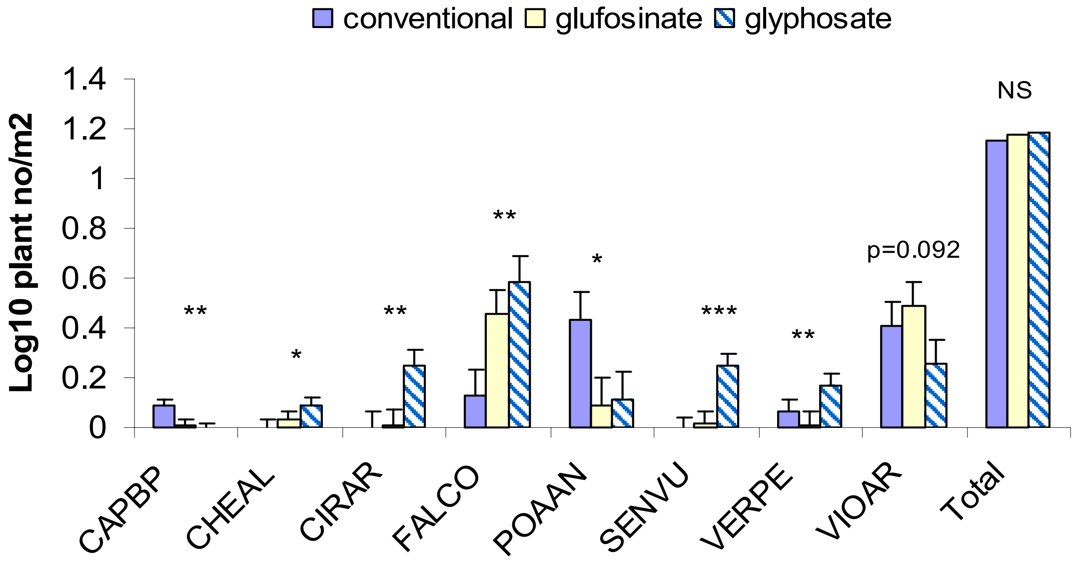


Figure 5.2.1.8. Broom's Barn Rotation 2 : post herbicide assessment of weed density in the herbicide treatments in year 4: (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

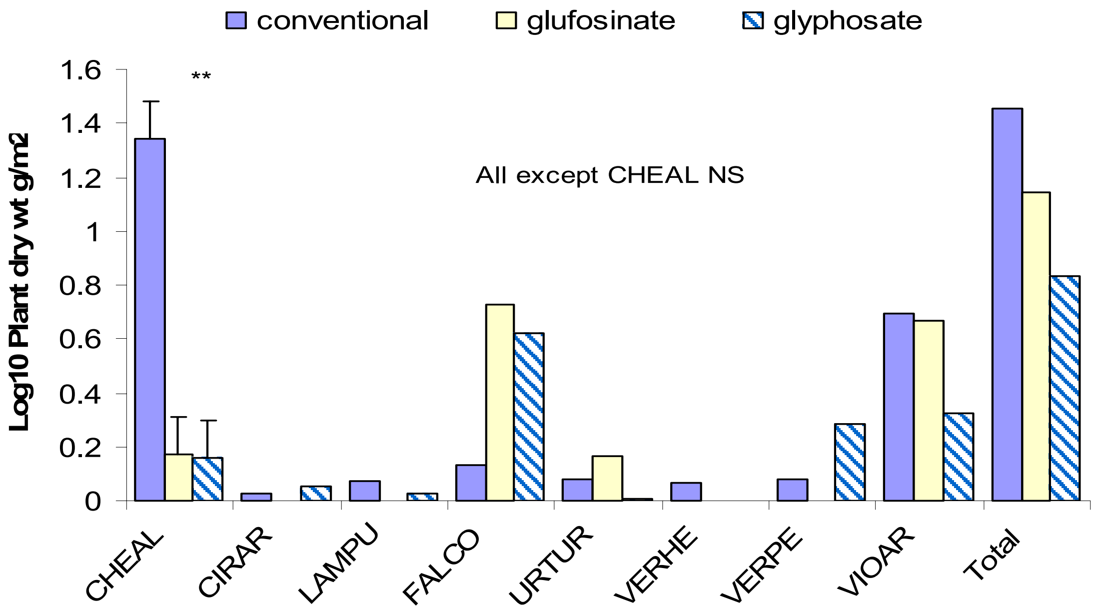


Figure 5.2.1.9. Broom's Barn Rotation 2 : biomass assessment in late summer in year 4: (NS = no significant effect of year 4 treatment: stars = significance, ** p<0.01)

Sugar beet yields

Yields in all cases were relatively low compared to commercial yields due to the early harvest; however, all were harvested on the same date and are therefore comparable for treatment effects.

Year 1 Sugar beet

Root yields at Broom's Barn in year 1 were lowest on the conventional plots, which had the greatest weed biomass (Fig. 5.2.1.10). However, yield was higher on the glufosinate plots compared to the glyphosate plots, despite them having a greater weed biomass. Statistical tests of the differences (p=0.007) indicated differences between all treatments. The treatment differences in sugar content appeared to be the inverse of the root yields; those with the highest root yield had the lowest sugar content (not significant difference). The overall result was no significant difference in sugar yield between the three treatments.

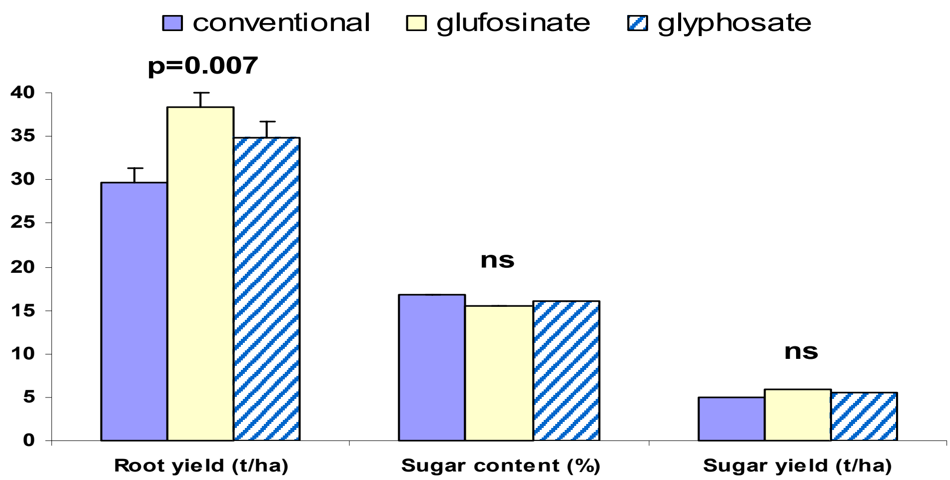


Fig. 5.2.1.10 Rotation 2 at Broom's Barn: yield and quality in harvested beet : responses to the herbicide treatments in year 1: (ns = no significant effect of treatment)

Year 4 Sugar beet

In year 4 the yields were analysed for any evidence of year 1 treatments effects on year 4 yields (Table 5.2.1.3). None was found, nor was there an interaction between year 1 and year 4 treatments. There was no difference in root or sugar yield between treatments. Sugar content differed significantly between treatments. The differences in crop populations mentioned earlier were evident at harvest and the number of roots in the harvest area was counted. Significant differences were found in the number of roots/ha and sugar content per root between year 4 treatments.

Table 5.2.1.3 Statistical significance of the year 1 and year 4 treatments on yield, sugar content and number of roots at Broom's Barn

Yield	TreatsYr1	TreatsYr4	Interaction
Roots	NS	NS	NS

Sugar	NS	NS	NS
Sugar %	NS	**	NS
Root number/ha	NS	**	NS
Sugar yield/plant	NS	***	NS

(NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<,0.001)

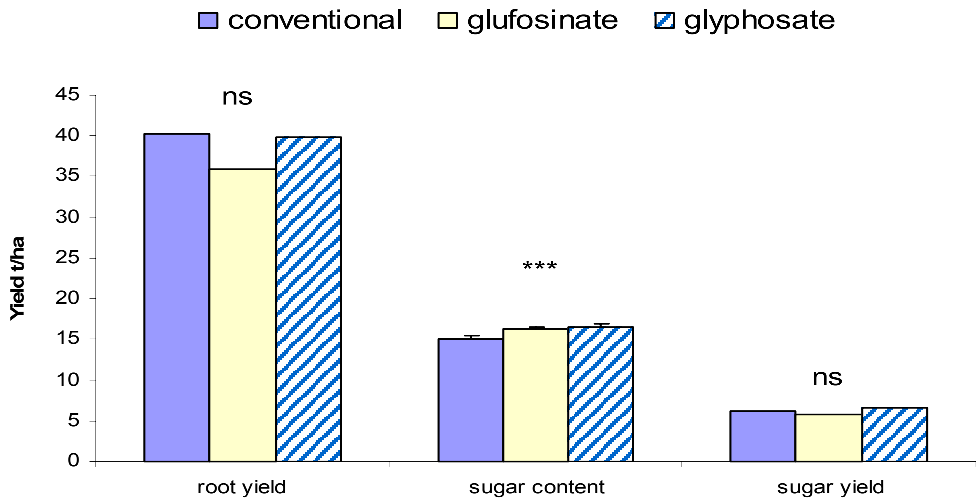


Fig. 5.2.1.11. Broom's Barn rotation 2 : Yield in year 4 following herbicide treatment: root and sugar yield and sugar content (NS = no significant effect of treatment: stars = significance ***p<0.001)

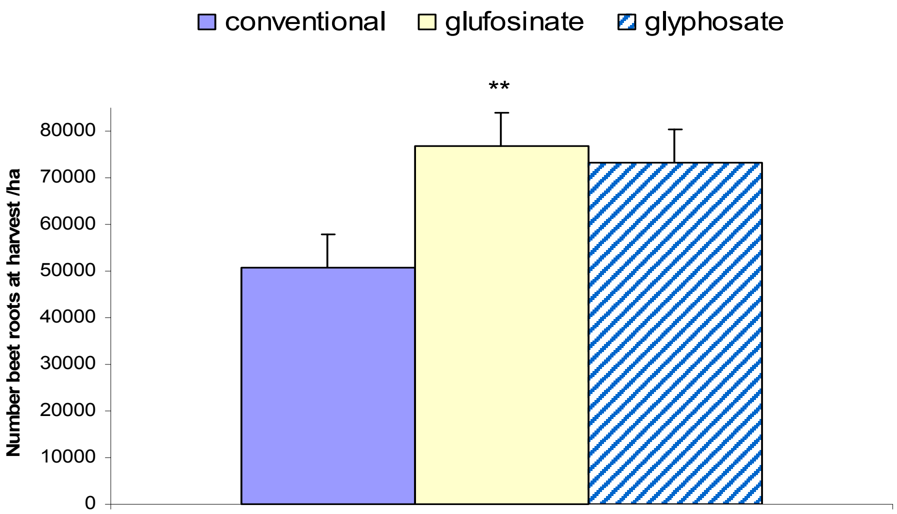


Fig. 5.2.1.12 Broom's Barn rotation 2: Yield following herbicide treatment in year 4: number of roots at harvest (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

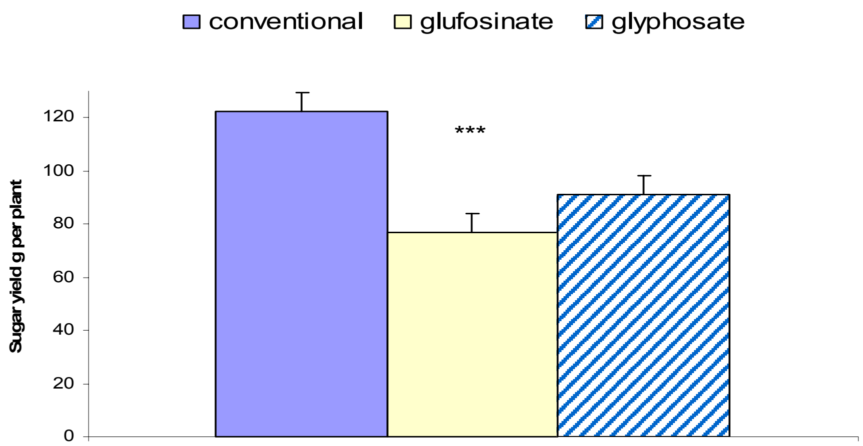


Fig. 5.2.1.13 Broom's Barn Rotation 2: Yield response to the herbicide treatments applied in year 4: sugar yield per root (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

There was no significant difference in root and sugar yields between treatments (Fig. 5.2.1.11). Although not significant, the yields were lowest in the glufosinate plots and may suggest that the second application of herbicide was late and the crop suffered weed competition. Sugar content was significantly lower in the conventional treatment than either the glufosinate or glyphosate treatments. At harvest, conventional plots had significantly fewer roots per unit area than the other treatments (Fig. 5.2.1.12) but, despite the lower sugar content, the conventional roots yielded more sugar per root (Fig. 5.2.1.13) due to their increased size.

Thus despite large losses in numbers, the conventional treatment compensated to such an extent that sugar yields (t/ha) were the same irrespective of treatment.

Seed bank data

This experiment had a similar weed flora to Rotation 3 at the same site, with *C. album* (CHEAL) being the dominant species. Other major species were *P. annua* (POAAN), *S. media* (STEME), *V. arvensis* (VIOAR) and a mixture of *Veronica persica* and *V. hederifolia* (VER spp). Overall 20 species were found in Year 1, prior to the start of the programme. Mean weed density was somewhat higher than in Rotation 3, being 9095 seeds/m^2. The vast majority was *C. album* (Fig. 5.2.1.14). There were no significant differences between treatments.

At the end of the experiment the seed bank had increased on all treatments, mainly due to changes in the level of C. *album*, up to 21,948 seeds/m^2. The seed bank changes appear to have been linked to the seed production in the two sugar beet years, as few weed seeds were produced in the barley.

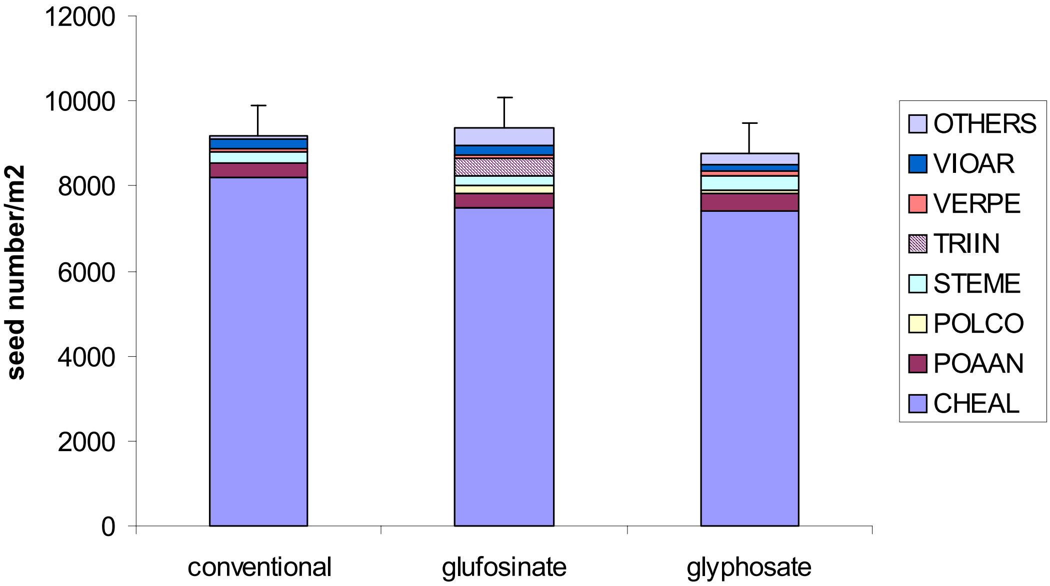
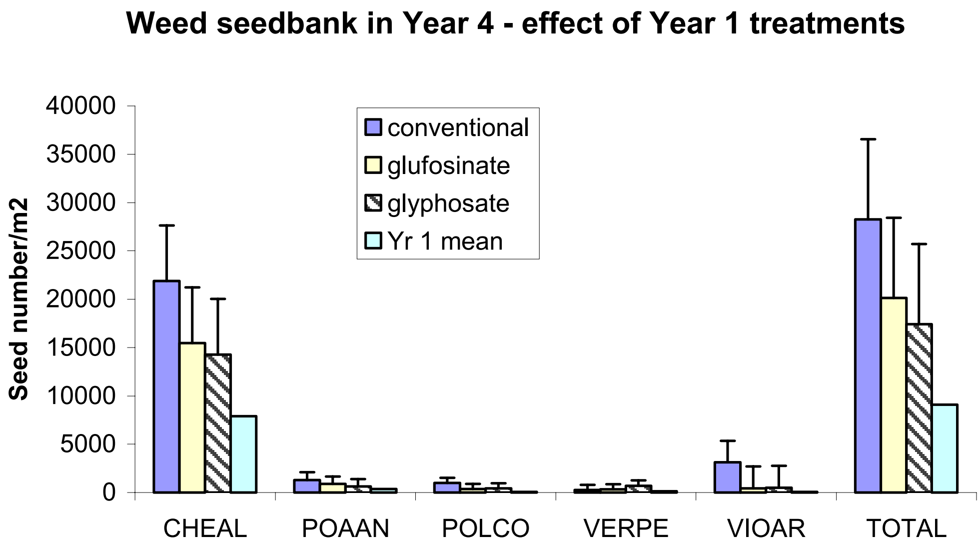


Fig. 5.2.1.14 Brooms Barn Rotation 2: Seed numbers/m^2 in the seedbank in autumn 1998 prior to the application of herbicide treatments (vertical bars are the SEDs of the total numbers)

Comparisons of the treatment effects on the main weed *C. album* are difficult because of the degree of variation in the data. However treatment differences from the year 4 treatments approached significance in year 4 (F prob. = 0.090) and the same trends are apparent from the year 1 treatments (Fig. 5.2.1.15). In both years the seed numbers were highest on the plots that had received the conventional treatment. Indeed, the seedbank on the plots receiving conventional treatments in both years 1 and 4 had over 36,000 seeds/m^2, compared to 7,000 – 23,000 seeds/m^2 on all the other treatments.



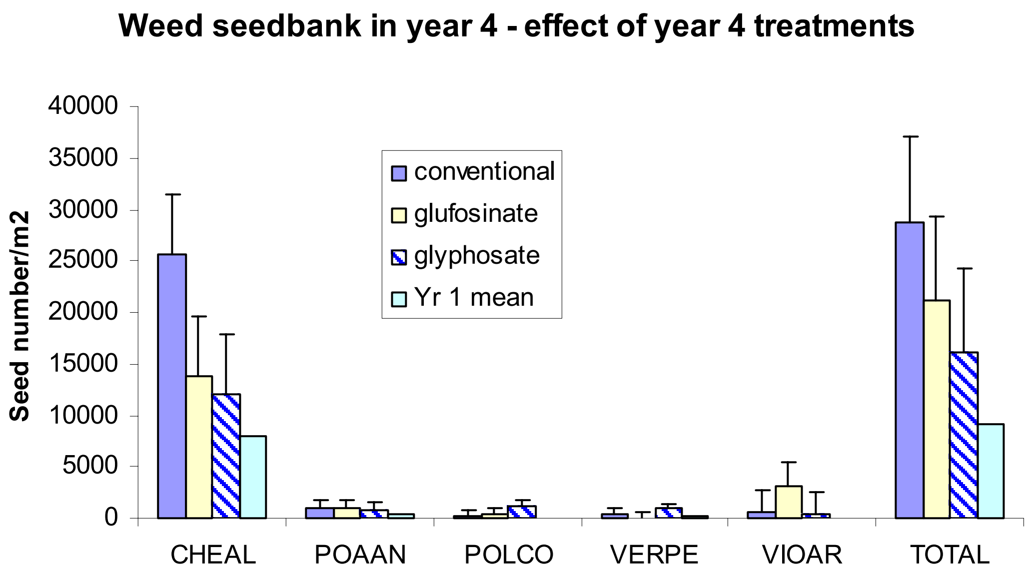


Figure 5.2.1.15 Brooms Barn rotation 2: Seed numbers in the seed bank in year 4, following treatments in years 1 & 4. Mean densities from year 1 given for comparison. Effects of year 1 and year 3 treatments presented separately. (Vertical bars are SEDs but all treatment effects were non-significant)

This increase in the seedbank on the conventionally treated plots concurs with the weed biomass data in year 4 (Fig 5.2.1.9) where there was a much greater quantity of *C. album* on the conventional treatment. The same trend is apparent in year 1 (Fig. 5.2.1.3) but the treatment differences were not statistically significant. The same two Figures show that there was appreciable biomass in both *P. convolvulus* and *V. arvensis* in one or both years, thus accounting for the increase in the seedbank of these two species.

The results from this rotation and site clearly show that less than complete weed control from a fecund species such as *C. album* can soon result in an appreciable increase in the seedbank.

Conclusions – Broom's Barn Rotation 2

In the two cereal years initial weed emergence in the autumn was moderately high, but effective weed control reduced the weed numbers to levels that were lower than those seen in the sugar beet. Thus, mean weed weights in summers year 1 to year 4 were 23.5, 0.4, 1.0 and 12.9 g/m^2, respectively. There was little evidence of differences from year 1 treatments carrying over into subsequent years, and any significant effects that were detected generally had very small values. The main treatment effects were in the years with sugar beet (years 1 and 4). Weed control was greatest in glyphosate plots and conventional crops in terms of weed numbers but no differences were evident in the subsequent weed biomass.

In year 4 the use of a pre-emergence herbicide prevented an analysis of effects from treatment in year 1, although the lack of effects in the two cereal years suggests these are unlikely. Overall, the year 4 treatments resulted in similar levels of weed control, although there were some treatment specific effects on some species. Differences in weed biomass at the end of the season were observed but these effects were non-significant due to the degree of variability between plots. The effects of the treatment differences in year 4 on yields were compounded by external factors such as the level of bird and mammal grazing seen on conventional plots, resulting in reduced crop competition and greater weed biomass (especially *C. album*).

5.2.2 Morley

The full four years of Rotation 2 was implemented at Morley, but there were problems with the data set collected in the sugar beet in year 1 as the nature of the information collected did not match that collected at the other sites and so was not comparable. Consequently they have been omitted from the report and this section now focuses simply on the year 4 sugar beet data, whilst including any impact the year 1 treatments may have had on weed infestations in year 4.

The main weeds to occur on the site were the spring emerging species *P. aviculare* (POLAV - knotgrass)*, P. convolvulus* (POLCO– black bindweed) (= *Fallopia convolvulus*) and *C. album* (CHEAL – fat hen), and the non-seasonally specific species *V. persica* (VERPE – common field-speedwell). *V. arvensis* (VIOAR – field pansy) and *P. annua* (POAAN – annual meadow-grass) were also present.

Year 4 – sugar beet

The first assessment was done on 29 May 2002, prior to the application of glufosinate and glyphosate. However, at this date the conventional plots had already received pre-emergence and early post-emergence herbicide treatments (Table 4.3.3)

Table 5.2.2.1. Morley Rotation 2: Effect of year 1 and year 4 treatments on the total number of weeds present (plants/m^2) prior to the application of glyphosate and glufosinate.

Year of treatment	Conventional	Glufosinate	Glyphosate	sed
Year 1	75.1	58.5	63.5	9.55 NS
Year 4	7.4	97.5	92.2	9.55 ***

There appeared to be no detectable carry over effect on weed numbers in year 4 from the treatments applied in year 1. As pointed out above the low weed number on the conventional plots as a result of treatment in year 4 is because the treatments had already been applied. Thus weed densities on the plots could be considered to be around 90 plants/m^2.

A further conventional treatment was applied on 6 June at the same time as applications of glyphosate and glufosinate. Weed densities post–treatment were recorded in mid July. In general, control of most species was high but 'others' showed appreciably poorer weed control from glufosinate (Fig 5.2.2.1). This was due to poor control of *V. arvensis* and *P. .annua.* This was reflected in significantly poorer total weed control for glufosinate. However, even here mean weed number on the glufosinate plots was only 20 plants/m^2. The factorial analyses could not detect any effect from the year 1 treatments.

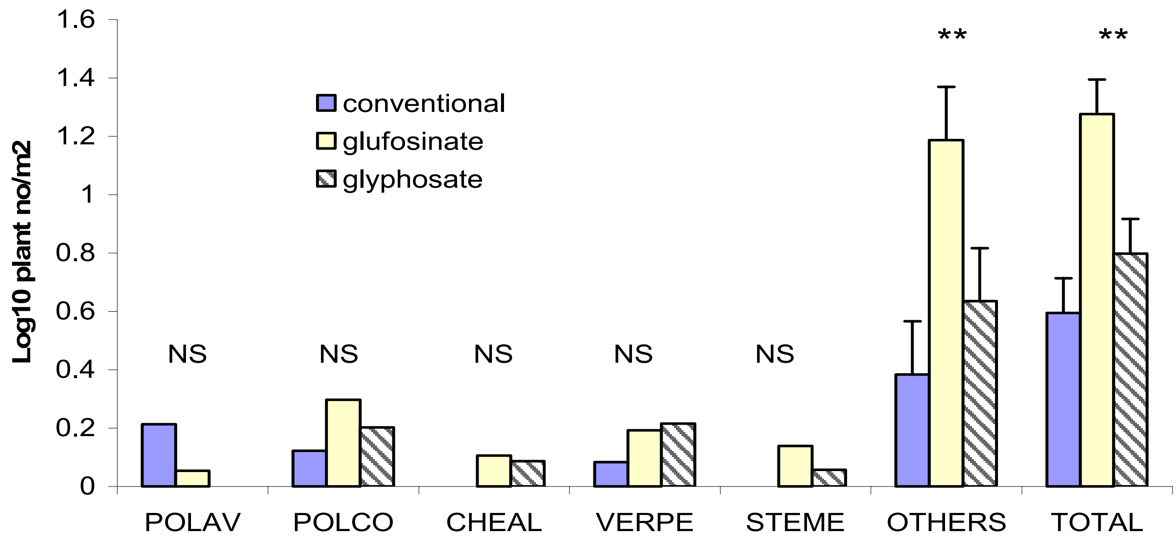


Fig. 5.2.2.1 Morley Rotation 2: response of weeds in year 4 to the herbicides applied in year 4: weed density post treatment (NS = no significant effect of treatment: stars = significance ** p<0.01)

At the end of August weed biomass was recorded on all plots. The poor control of *P. annua* and *V. arvensis* from glufosinate noted in the earlier plant counts was also reflected in the weed biomass (Fig 5.2.2.2). The remaining species were well controlled. No responses to the year 1 treatments were detected. The conventional and glyphosate treatments both gave high levels of weed control, whilst the glufosinate was somewhat less effective. However weed biomass even on the glufosinate plots was not high.

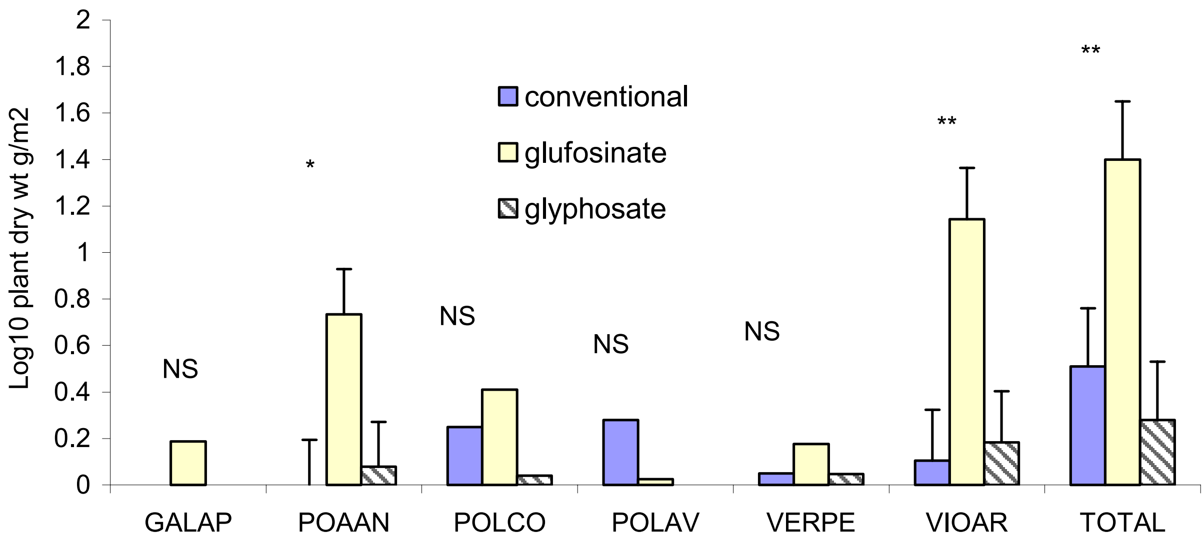


Fig. 5.2.2.2 Morley Rotation 2: response of weeds in year 4 to the herbicides applied in year 4: weed biomass post treatment (NS = no significant effect of treatment: stars = significance *p<0.05, p<0.01)**

Sugar Beet yields

Best yields appeared to be achieved by the conventional variety but the statistical significance was only p=0.067. Despite the poorer weed control on the glufosinate plots yield of the glyphosate and glufosinate tolerant cultivars were similar. Sugar contents were significantly lower on the conventional variety. Sugar yields reflected the increased yield of the conventional variety and its lower sugar content and thus sugar yields were not different across the three varieties. Some yellowing of the treated foliage of the glufosinate tolerant beet was observed after application of glufosinate which resulted in some temporary reduction in crop vigour.

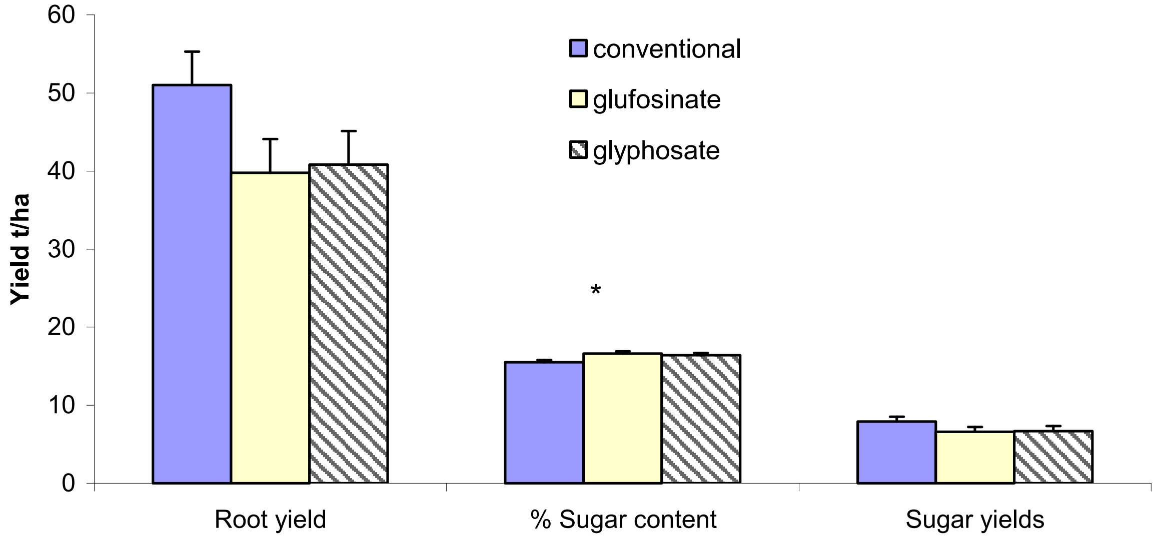


Fig. 5.2.2.3. Morley R2 year 4: Sugar beet root yields (t/ha) for the three cultivars, % sugar contents and sugar yields (t/ha). (NS = no significant effect of treatment: stars = significance *p<0.05, p<0.01)**

Conclusion

One application of glufosinate resulted in inferior levels of weed control compared to the other two treatments. A single application of glyphosate gave similar levels of weed control compared to three applications of several products on the conventional.

5.2.3. Conclusions from Rotation 2.

Treatment differences were small at Broom's Barn though glufosinate, even after 2 applications, was marginally poorer in year 4. This difference was accentuated at Morley where there was only one application of glufosinate.

At both sites a single application of glyphosate was as effective as the multiple conventional treatments.

At Brooms Barn weed survival in the cereal crops was less than in the beet crops.

No consistent differences were seen in the root yields and sugar yields between the different treatments at both sites.

5.3 Rotation 3 (Oilseed rape - cereal - sugar beet - cereal)

In this rotation oilseed rape (two herbicide tolerant and one conventional) was grown in the first year, winter cereal in the second year, sugar beet (two herbicide tolerant and one conventional) in the third year and winter cereal again in the final year. Weeds were assessed in all crops as described previously.

5.3.1 Broom's Barn

5.3.2

The main weeds in Rotation 3 at Broom's Barn were *Avena fatua* (AVEFA – wild oat), *Capsella bursa-pastoris* (CAPBP – shepherd's purse), *Matricaria* spp. (MATSp – mayweeds), *Poa* spp. (POASp – meadow-grasses), *Stellaria media* (STEME – common chickweed), *Veronica* spp. (VERSp – speedwells) and *Viola arvensis* (VIOAR – field pansy). *Brassica napa* (BRANA – oilseed rape) volunteers were present after year 1 and *Chenopodium album* (CHEAL – fat hen) was present after year 3.

Year 1 winter oilseed rape

The four herbicide treatments were applied to the rape in the spring of 1999 (Table 4.3.2). Poor growth and wet weather over the winter had prevented earlier application. Weeds were already present and counts were taken immediately after herbicide application but before the herbicides had begun to have an effect. Snow fell on the experiment immediately after spraying, and delayed counts for a few days. The commonest weeds were *S. media* and *A. fatua* (Table 5.3.1.1). Weed densities were moderately high at nearly 50 plants/m^2.

Table 5.3.1.1 Broom's Barn Rotation 3: Density of the major weeds present prior to treatment in spring 1999

Species	Mean weed density in spring 1999 (plants/m^2)
Avena fatua	12.1
Matricaria spp.	1.7
Stellaria media	8.2
Veronica spp.	5.6
Viola arvensis	4.7
Other grasses	7.5
Other broad-leaved weeds	6.0
Total weeds	47.8

Plots sown with the imazamox tolerant variety were treated with the same conventional herbicides as the conventional plots. As varietal effects are likely to be small compared to herbicidal effects, data from the imazamox and conventional treatments have been merged and will both be presented as the conventional treatment. Following herbicide application of the treatments (glyphosate, glufosinate and conventional (benazolin and clopyralid)) significant treatment effects were seen on the numbers of several species (Fig 5.3.1.1). Plant numbers were highest on the conventional plots, whereas very few were recorded on either the glyphosate or glufosinate treatments for *A. fatua*, *S. media*, *Veronica* spp., other broad-leaved weeds and total weeds. The difference was due to differences in weed control spectrum and the application timing of the herbicides. The conventional herbicide (benazolin and clopyralid) has a limited weed spectrum and spring application reduced activity still further.

Plant biomass was significantly greater on conventional plots, compared to the glufosinate and glyphosate plots for several species and total weeds. The significant effects on numbers of *S. media* and *Veronica* spp were carried through to biomass (Fig 5.3.1.2). There had been few *Poa* spp. counted in the early summer, but the biomass assessment showed significant treatment differences. In contrast, significant effects on plant numbers at the spring counts on *A. fatua* and other broad-leaved weeds were not carried through to biomass. Overall weed biomass averaged 14 g/m^2, which is low in the context of weeds in rape, where at this time of the year the crop can weigh over 1000 g/m^2.

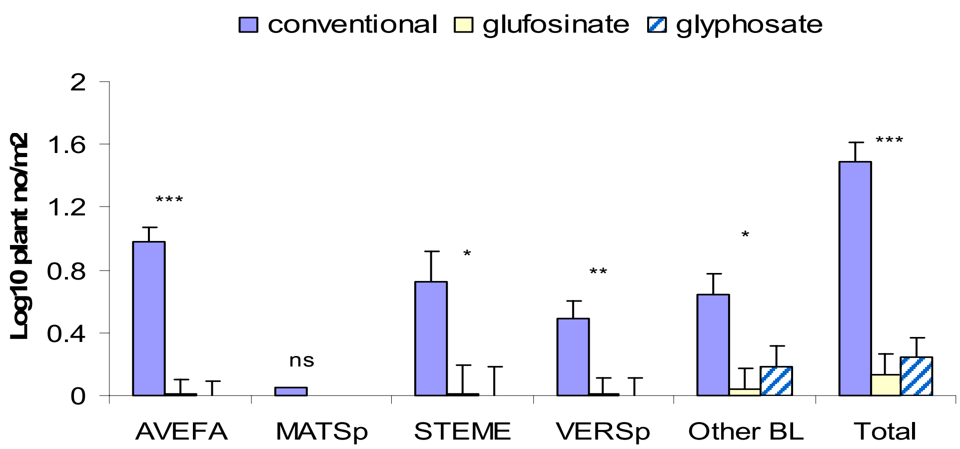


Fig 5.3.1.1 Broom's Barn Rotation 3: Weed numbers (Log10) in Spring year 1 post herbicide application. Vertical bars = 1 x sed (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

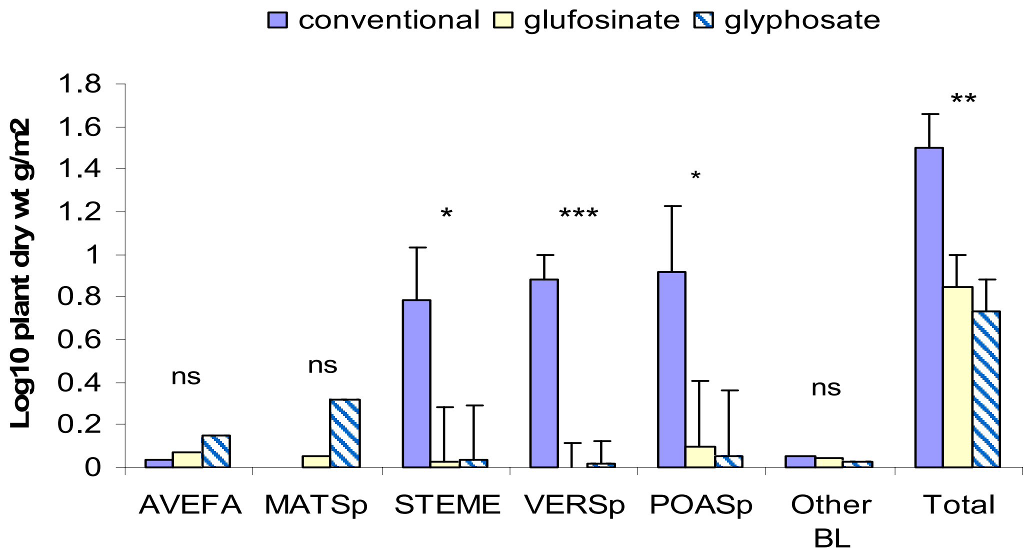


Fig 5.3.1.2 Broom's Barn Rotation 3: Weed biomass (Log10) in summer year 1 after herbicide application. Vertical bars = 1 x sed (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

Year 2 winter barley

The plots were drilled in the autumn of 1999 with winter barley and were treated uniformly all receiving the standard farm weed control programme (Table 10.2.6). To check for carry over effects from year one, weed counts were taken and analysed according to the application of these treatments. In the autumn (pre-treatment), effects of year 1 treatments were seen on *S. media* (p=0.053), *Veronica* species (p=0.052) and total weeds (p=0.011). Densities on the conventional plots were significantly higher than on the glufosinate or glyphosate plots. There was no significant difference between the densities on the glufosinate and glyphosate plots. Overall weed counts were moderate at 38 plants/m^2.

Weed control was very effective and in the spring counts overall weed densities were reduced to very low levels (3.6/m^2). The main species were *V. arvensis*, *S. media*, *Veronica hederifolia*, *C. bursa-pastoris* and *Galium aparine* (Fig 5.3.1.3). Most oilseed rape volunteers (Plate 5.3.4.1) were found on the glyphosate plots (1.3/m^2) and significantly fewer on the glufosinate and conventional plots (1.2 and 1.1/m^2 resp.). These differences link to the numbers of seed shed at harvest in year 1 (Fig, 6.1.2.1). The conventional plots had apparently the greatest total density, but differences between the treatments were not significant (p=0.534).

Plate 5.3.4.1. Broom's Barn Rotation 3. Oilseed rape volunteers in the second year barley crop.

Total weed biomass, collected just prior to harvest, was low (mean=1.7 g DM/m^2). No rape plants were harvested and total weed biomass was not significantly affected by the treatments (p=0.226) despite the apparently lower biomass on the plots previously treated with glyphosate (Fig 5.3.1.4).

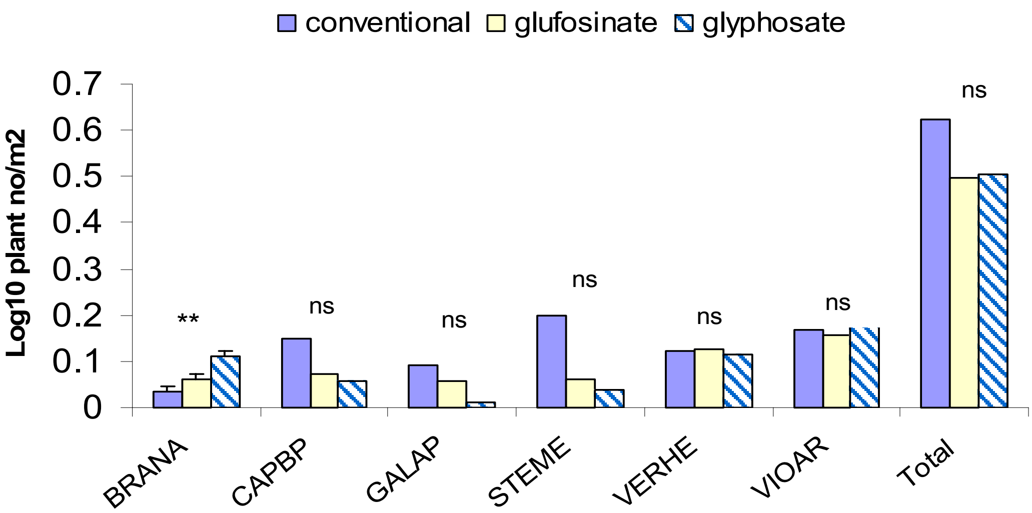


Fig 5.3.1.3 Broom's Barn Rotation 3: Weed numbers (Log10) in spring year 2 post herbicide application. Vertical bars = 1 x sed (NS = no significant effect of treatment)

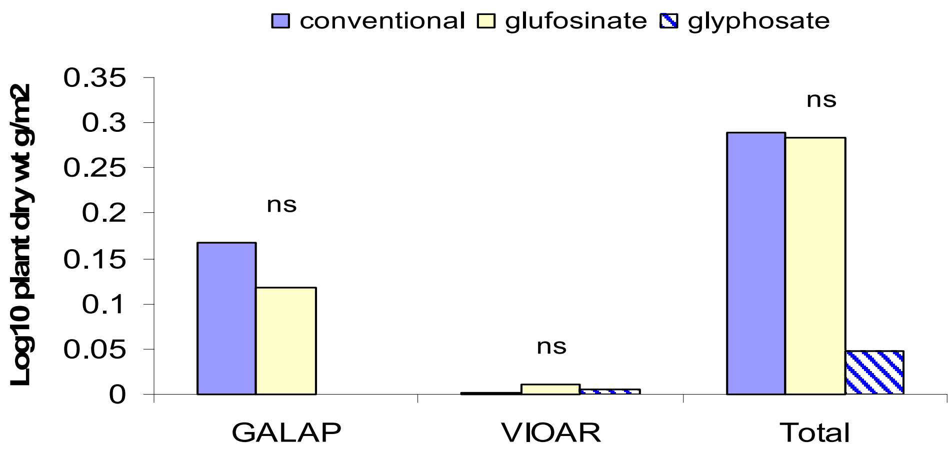


Fig 5.3.1.4 Broom's Barn Rotation 3: Weed biomass (Log10) in spring year 2 post herbicide application. Vertical bars = 1 x sed (NS = no significant effect of treatment)

Year 3 Sugar beet

Counts taken prior to application of herbicides in 2001 showed no significant differences between the plots based on year 3 treatments (Table 5.3.1.2). Non-significant effects were seen on *Cirsium arvense* (p=0.068) but counts were very low (<0.1 /m^2) and it was only present on 17% of plots. Total weed densities were moderate at 35 plants /m^2 but high if the number of *B. napus* volunteers are included (150 plants/m^2) and beet establishment varied slightly with variety (p=0.072). Crop densities were highest for the glufosinate variety, lowest for the conventional variety and averaged 96,000 per ha (range 89-102,000/ha).

Table 5.3.1.2 Broom's Barn Rotation 3: Statistical significance of the year 1 and year 3 treatments on weed density (Log10 plants/m^2) pre-treatment.

Weed	TreatsYr1	TreatsYr3	Interaction	Mean count
BRANA	**	NS	NS	96.3
CAPBP	p=0.074	NS	NS	1.7
CIRAR	NS	p=0.068	NS	0.05
POASp	p=0.059	NS	NS	1.9
STEME	**	NS	NS	2.0
VERsum	***	NS	NS	4.2
TOTAL	**	NS	NS	35.1

(NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

Effects of year 1 treatments were seen in *B. napus*, *C. bursa-pastoris, Poa* spp., *S. media*, total *Veronica* spp. and for the total weeds which included *B. napus* volunteers (Table 5.3.1.2; Fig. 5.3.1.5). Relatively large numbers of *B. napus* volunteers were also found (96 /m^2) and there were differences between treatments. Volunteer densities were more than twice as high on the glufosinate and glyphosate tolerant variety plots than on the conventional ones and the greatest densities (187 /m^2) were seen on the glufosinate plots. These differences are directly related to the amounts of seed shed at harvest in year 1. There were no year 1*year 3 treatment interactions.

Following herbicide application, the number of total weeds was reduced by 50%. A number of significant effects were seen for both year 1, year 3 and year1*year3 treatments (Table 5.3.1.3). Significant effects seen on species with average counts of less than 1 /m^2 have not been included. Effects due to year 1 treatments were seen on *Poa* spp., *S. media* and total *Veronica* spp.. Strong effects were also seen for year 1, year 3 and year 1*year 3 treatments in the numbers of *B. napus* volunteers. Significant effects of year 3 treatments were only seen on *C. album* which may indicate that the majority of species present were equally susceptible to the herbicides used in the three treatments. The total number of weeds was most affected by year 1 treatments although a non-significant effect (p=0.089) was seen in year 3. There was no interaction of year 1 and year 3 treatments on total weed densities.

Table 5.3.1.3 Broom's Barn Rotation 3: Statistical significance of the year 1 and year 3 treatments on weed density (plants/m^2) post GM treatment.

Weed	TreatsYr1	TreatsYr3	Interaction	Mean count (plants/m^2)
BRANA	**	***	**	35.4
CHEAL	NS	***	**	3.2
POASp	***	NS	NS	2.4
STEME	**	NS	NS	1.0
VERsum	***	NS	NS	2.5
TOTAL	**	0.087	NS	15.6

(NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

After herbicide application in year 3 the greatest effects were due to the year 1 treatments, where in the majority of cases the counts were greatest on the plots which had contained conventionally treated rape (Fig. 5.3.1.5). Control in most cases was similar between glufosinate and glyphosate plots. The exception being in the number of rape volunteers which was related to the variety, and hence the seed shed, in year 1. Year 3 treatment effects were confined to *B. napus* and *C. album* (Fig. 5.3.1.6). In both cases the conventional treatment was weaker, leading to greater densities, compared to either the glufosinate or glyphosate treatments. The treatment difference in numbers of *C. album* was insufficient to produce a significant treatment effect in total weed numbers (p=0.089).

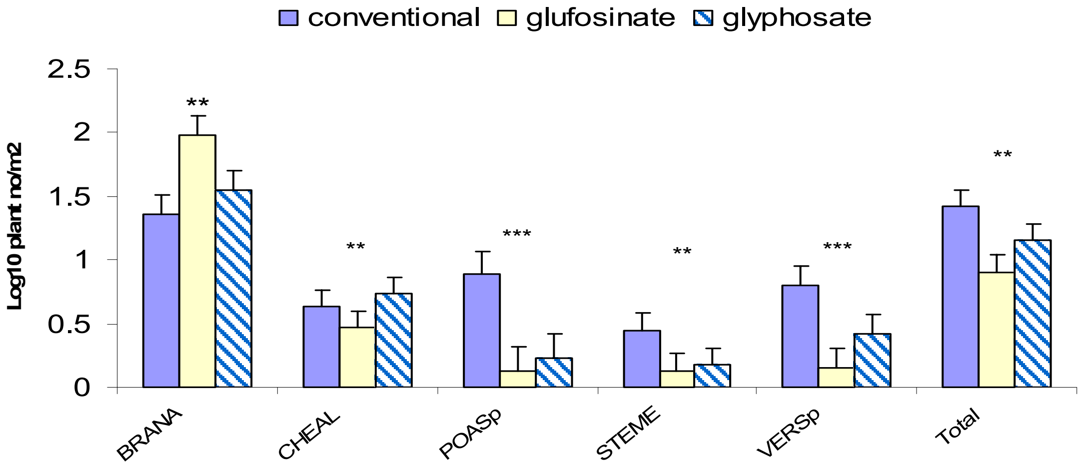


Fig 5.3.1.5 Broom's Barn Rotation 3: Effect of year 1 treatments on weed density (Log10) in year 3 post herbicide application. Vertical bars = 1 x sed (NS = no significant effect of treatment: stars = significance * p<0.05, ** p<,0.01, ***p<0.001)

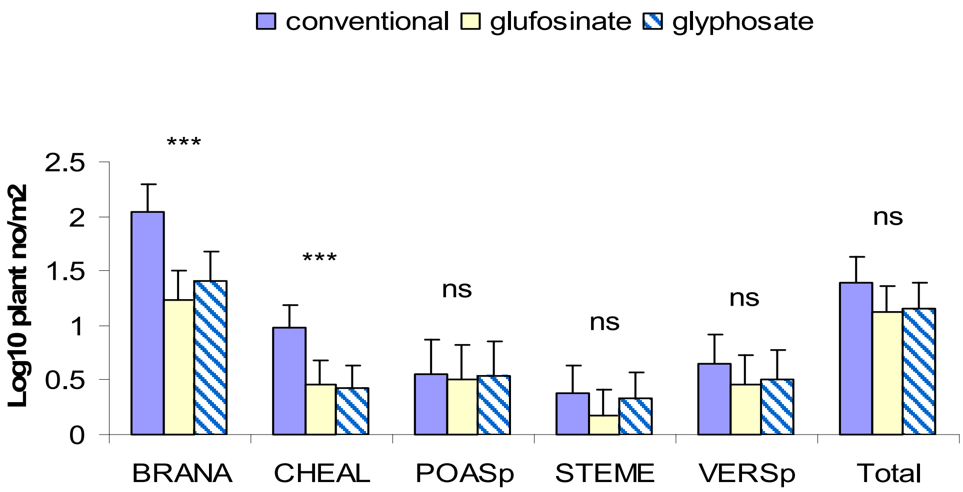


Fig. 5.3.1.6. Broom's Barn Rotation 3: Effect of year 3 treatments on weed density (Log10) in year 3, post herbicide application. Vertical bars = 1 x sed (NS = no significant effect of treatment: stars = significance ***p<0.001)

Numbers of *B. napus* volunteers were greatest on the conventional sugar beet plots (Fig 5.3.1.7) illustrating the problems of controlling oilseed rape in sugar beet rotations. On the conventional beet plots, volunteers of herbicide tolerant rape were more numerous than conventional rape volunteers, but this was due largely to differences in the seedbank from seeds shed in year 1 and not to a herbicidal effect. The numbers of rape volunteers on both the glufosinate and glyphosate resistant beet plots were greatest where the rape variety in year 1 had been tolerant to the same herbicide. Data of the control of volunteers, comparing post herbicide and pre herbicide counts, confirm this trend (Fig 5.3.1.8). Where it is known that the volunteers are tolerant of the herbicide, poor control can be attributed to tolerance, but high counts post herbicide will also include a number of plants which had emerged in later germination flushes. A wide germination window is one of the reasons why oilseed rape is difficult to control in sugar beet.

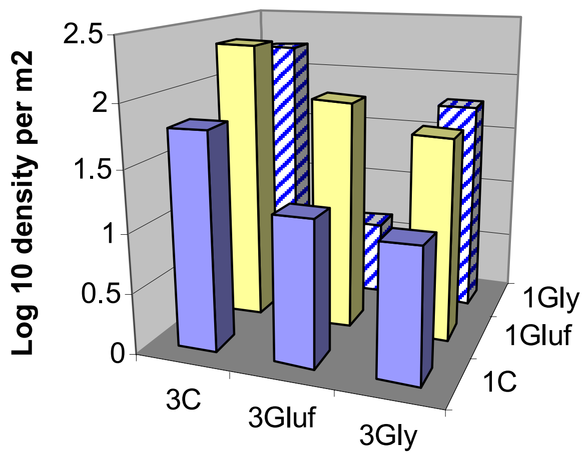


Fig 5.3.1.7 Broom's Barn Rotation 3: Density (Log10) of *B. napus* volunteers in year 3 post herbicide application based on year 1 and year 3 treatments (SED=0.275). (C = conventional, Gluf = glufosinate, Gly = glyphosate)

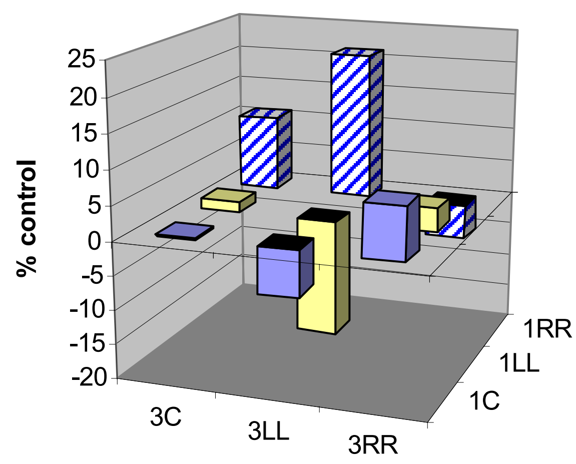


Fig 5.3.1.8 Broom's Barn Rotation 3: Control (%) of rape volunteers in year 3 post herbicide application, compared to pre herbicide counts, based on year 1 and year 3 treatments . (C = conventional, LL = glufosinate, RR = glyphosate)

Treatment effects on *C. album* in year 3 suggested an interaction with year 1 treatments (Table 5.3.1.3). This was surprising as the weed was not recorded as being present in year 1 and probably reflects spatial variability in the distribution of the weed across the site.

Effects on biomass principally reflected the effects on plant numbers seen post herbicide application (Fig 5.3.1.9 and Table 5.3.1.4). Effects on species with very low weights (<0.4 g DM/m^2) are not included. The weed having the greatest impact on the total weed weight was *C. album* with a mean of 11 g DM/m^2. Despite relatively high counts of *B. napus* volunteers post herbicide their contribution to the biomass was relatively small, since many of the rape plants emerged late and consequently were small when they were harvested. Late flushes of rape plants were shaded by the beet canopy and remained at the rosette stage.

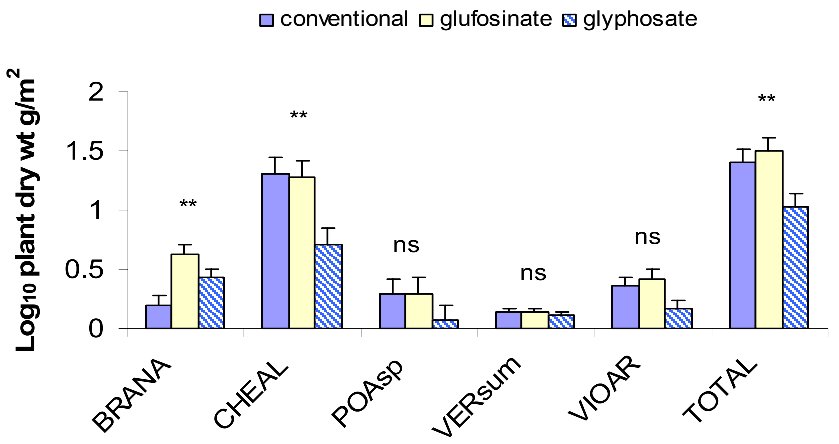


Fig. 5.3.1.9 Broom's Barn Rotation 3: Weed biomass (Log10 g DM/m^2) in year 3 post herbicide application based on year 3 treatments. Vertical bars = 1 x sed (NS = no significant effect of treatment: stars = significance ** p>0.01)

Table 5.3.1.4 Broom's Barn Rotation 3: Statistical significance of the year 1 and year 3 treatments on weed biomass (Log10 g DM/m^2) .

Weed	TreatsYr1	TreatsYr3	Interaction	Mean weight
BRANA	**	**	**	1.63
CHEAL	NS	**	***	11.6
POASp	0.078	NS	NS	0.7
VERsum	***	NS	NS	0.4
VIOAR	NS	0.073	NS	1.1
TOTAL	NS	**	**	19.2

(NS = no significant effect of treatment: stars = significance * p<0.05, ** p<0.01, ***p<0.001)

Root yields were very different between the varieties. The lowest yields were from the glufosinate tolerant variety and the highest yields were from the conventional variety (Fig. 5.3.1.10). As is usually the case the greater root yields had the lower sugar content and the content of the glufosinate tolerant variety was the greater. The higher sugar content however did not compensate for the lower root yield and overall the sugar yields exhibited the same treatment differences as the root yields.

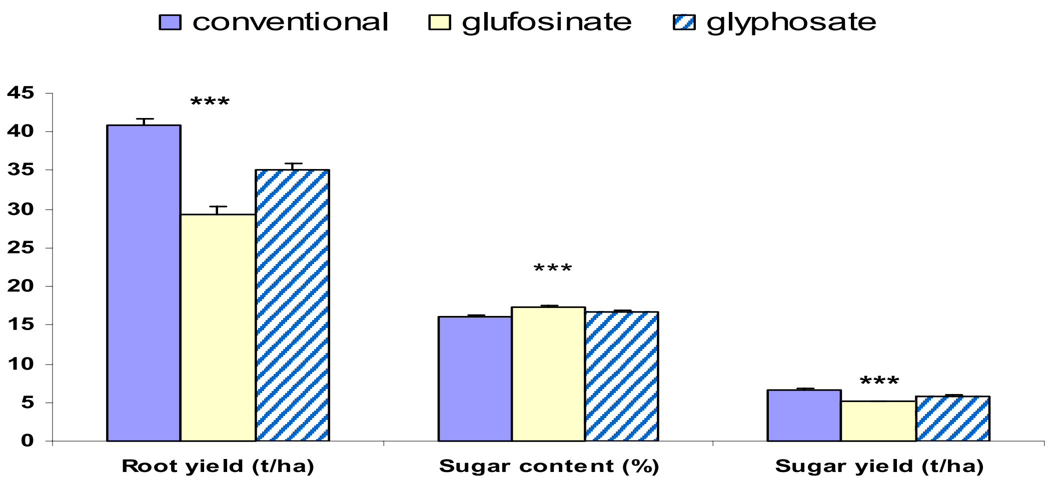


Fig 5.3.1.10. Broom's Barn Rotation 3: Root yield, sugar content and sugar yield in year 3 following treatments applied in year 3. (stars = significance ***$p<0.001$)

Year 4 Winter barley

In the autumn of year 4 winter barley was sown and herbicide counts were taken before herbicides were applied. Total weed densities were higher than in year 2 with mean counts of 59 plants/m^2. Treatment effects were largely attributable to treatments in year 1 with significant effects on *B. napus*, *Poa* spp., *S. media*, *Veronica* spp. and total weeds. Effects on species with low densities are not included. No significant effects of year 3 treatments were evident although the *Sonchus* spp. indicated some effects of year 1 (p=0.092) and year 3 (p=0.074) treatments.

Following herbicide application, the only significant treatment effects at the spring count were seen in *B. napus* volunteers, which continued to show a year 1 treatment effect. Total weed numbers did not show a significant treatment effect and densities fell to 4.6 plants/m^2. The effect on *B. napus* was no longer evident at the biomass sampling, and neither a single species nor total weed biomass showed significant treatment effects of year 1, year 3 or the interaction. Total weed biomass was low at 1.1 g DM/m^2 and *B. napus* contributed only 0.03 g DM/m^2.

Summary

Initial weed populations were moderate to low due to a history of good weed control at this site. In the first year rape was absent as a weed since none had been grown previously. Weed control in the first year highlighted the relatively poor performance achieved using this conventional herbicide and this contrasted strongly with relatively high efficacy of both glufosinate and glyphosate. The poor control from the conventional was primarily due to weather delaying treatment until February, which limited product choice and reduced the performance of the products applied. Treatment effects seen on weed numbers were largely carried through to weed biomass at harvest. Differences in rape seed shedding between varieties at harvest was the basis for some of the subsequent differences seen in the numbers of rape volunteers in following crops (Fig. 6.1.2.1) In the winter barley initial weed emergence was at similar levels to those seen in year 1, but herbicide application reduced weed numbers to very low levels and this resulted in low weed biomass. Treatment effects seen for particular species were carried through the barley in year 2 and were prominent in the sugar beet in year 3. In fact, more treatment effects could be related to year 1 treatments than year 3 suggesting that relative efficacy on the spectrum of weeds present at Broom's Barn varied little between the conventional sugar beet herbicides, glufosinate and glyphosate. Numbers of rape volunteers were higher in the barley in year 2 than the sugar beet in year 3, but herbicides reduced the number of volunteers in the cereal and perhaps through shading or another effect of micro-climate they did not re-emerge in large numbers. Rape volunteers were present in the sugar beet throughout the season although they remained as a rosette and did not contribute much to the total biomass. The sugar beet year also saw *C. album* feature as an important weed, the first time in this rotation due to it being the only spring sown crop. In the final cereal year total weed emergence was higher than in year 2 or 3. The dominant species were again those which had been important in year 1 and treatment effects for year 1 were still evident. *C. album* was not an important weed in this year due to winter sowing. Herbicides were again effective and resulted in low weed populations and the only significant effects post application were those for rape volunteers. Overall weed control was highest in the two cereal years and was lowest in the beet in year 3 (Fig 5.3.1 11).

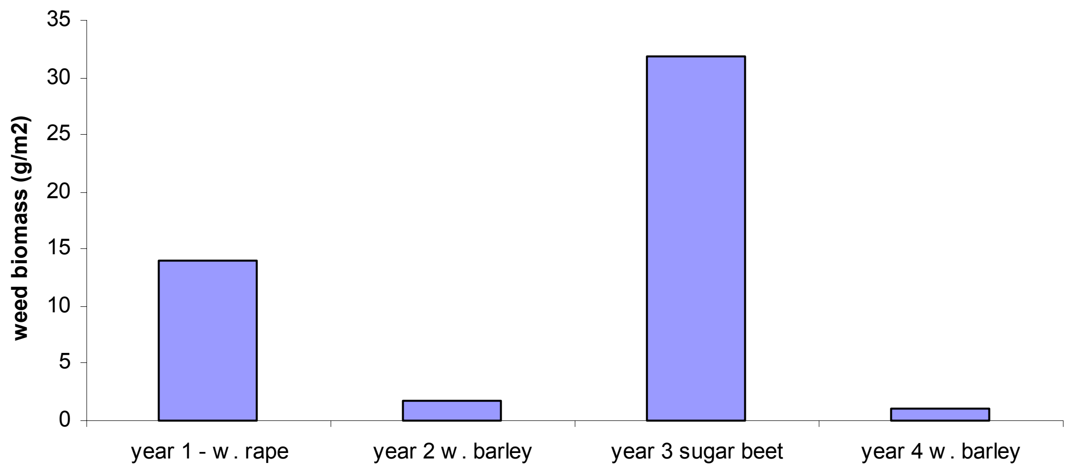


Fig. 5.3.1.11 Broom's Barn Rotation 3: Mean weed biomass in summer in each of the four years.

5.3.2 NIAB Rotation 3

The main weeds to occur on Rotation 3 at NIAB over all years were *Capsella bursa-pastoris* (CAPBP - shepherds purse), *Poa annua* (POAAN - annual meadow-grass), *Urtica urens* (URTUR - annual nettle), *Triticum aestivum* (TRIAE - wheat volunteers) and *Viola arvensis* (VIOAR - field pansy). Some additional spring germinating weeds such as *Chenopodium album* (CHEAL - fat hen) and *Polygonum aviculare* (POLAV - knotgrass) were recorded in the sugar beet crop in year 3.

Year 1 - oilseed rape

Three herbicide treatments were applied to the rape in the autumn of 1998 (Table 4.3.2). In rotation 3 at NIAB no imazamox was applied to the IMI tolerant rape, and an additional and identical conventional treatment was substituted. The main weeds present prior to treatment in the autumn are shown in Table 5.3.2.1. The commonest weeds were *P. annua* with an overall mean density of 64 plants/m^2 and *C. bursa-pastoris* with an overall mean density of 38 plants/m^2. There was also a high density of *T. aestivum* volunteers arising from the previous winter wheat crop. There was a significant difference in the levels of *Solanum nigrum* across the treatments due to the low density recorded in the glufosinate treated plots ($p<0.05$).

Plate 5.3.2.1. NIAB Rotation 3. Oilseed rape at 4-6 leaf stage infested with wheat volunteers prior to glufosinate/glyphosate application.

The spring weed assessment (Fig. 5.3.2.1) showed that overall mean weed numbers were reduced from 179 plants/m^2 to 64 plants/m^2. Overall, fewer weeds appeared to be present on the glyphosate treated plots. Notably there were significant differences between treatments in numbers of *T. aestivum*; the highest numbers being recorded in the glufosinate treatment. The glyphosate treatment appeared to give the best control of *V. arvensis* and of *P. annua* and poorest control of *C. bursa-pastoris* but the differences were not statistically supported. A further significant difference ($p<0.001$) was apparent with *Senecio vulgaris* due to higher numbers in the conventional treatment although densities of this weed were low (<0.25 plants/m^2) and thus of minor biological significance.

Plate 5.3.2.2. NIAB Rotation 3. Oilseed rape at 4-6 leaf stage post conventional herbicide treatment showing wheat volunteer control.

Table 5.3.2.1. NIAB Rotation 3: the main weeds present prior to treatment in the autumn

Species	Mean weed density in autumn 1998 (plants/m^2)
C. bursa-pastoris	38.4
P. annua	63.9
T. aestivum	7.65
U. urens	44.0
V. arvensis	1.66
Total weeds	179.5

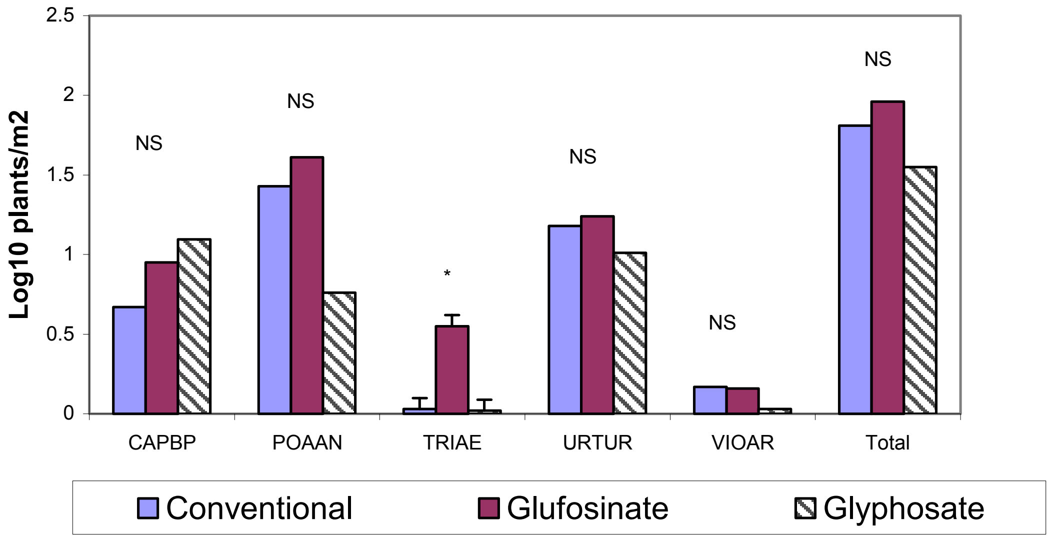


Figure 5.3.2.1 NIAB Rotation 3: response of weeds to the herbicides applied in year 1, spring assessment of weed density 1999 (NS = no significant effect of treatment; stars = significance *p<0.05, vertical bars = 1 x sed)

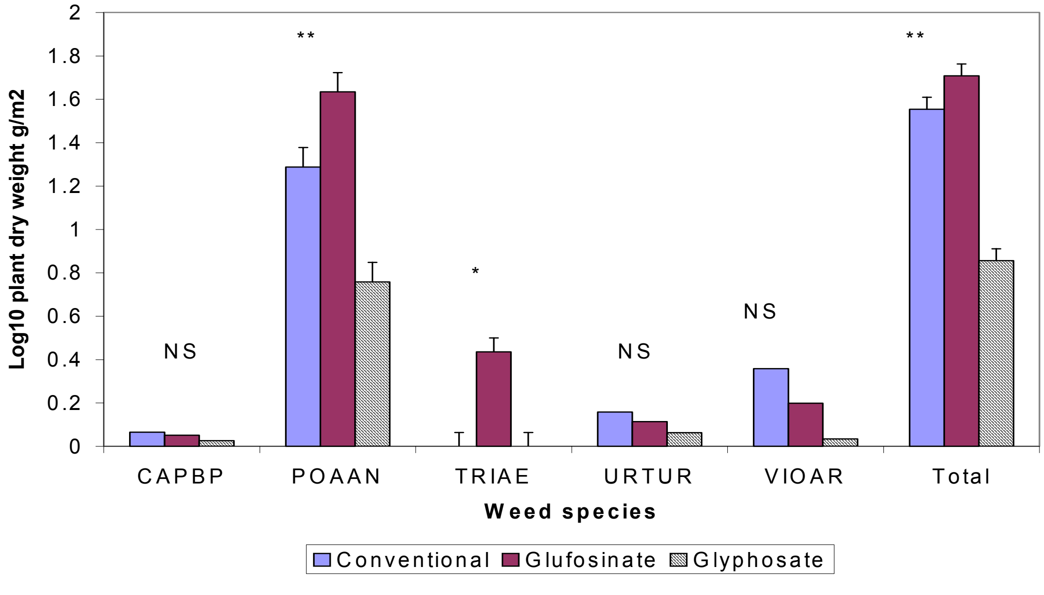


Figure 5.3.2.2 NIAB Rotation 3: Response of weeds to the herbicides applied in year 1; weed biomass assessment in summer 1999 (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, vertical bars = 1 x sed)

The biomass assessment (Fig. 5.3.2.2) showed that the glyphosate treatment produced significantly less total weeds than the other treatments. The two grass weeds present *T. aestivum* and *P. annua* were most abundant in the glufosinate treatment, reflecting the differences seen in the spring weed counts. Significantly better control of these weeds was recorded in the conventional and glyphosate treatments.

Year 2 - Winter wheat

The plots were treated uniformly in year two, receiving a standard winter wheat weed control programme (Tables 10.2.1-10.2.10). Weed numbers were relatively low in autumn 1999, the mean plant density across all treatments was 77.1 plants/m^2. The most frequently occurring weeds were *C. bursa- pastoris*, *P. annua*, *S. media*, *U. urens*, *V. hederifolia* and *V. arvensis*. No significant effects on these species, from the treatments in the previous year, were recorded

The main weeds present at the spring weed assessment were *V. hederifolia* and *V. arvensis*. Treatments in the winter had been highly effective and no significant effects of the previous treatments were detected. Very low weed biomass was recorded in the summer of 2000, an overall mean of 0.16 g/m^2 and no significant differences between the former rape treatments were detected.

Year 3 - sugar beet

Three herbicide programmes were used in the sugar beet; conventional, glufosinate and glyphosate, details of the treatments are shown in Table 4.3.2. All the conventional plots were weeded with a steerage hoe in May 2001 due to excessive weed growth in these plots. The assessments were carried out pre herbicide treatment and post herbicide treatment, the post herbicide assessment was carried out after all weed control measures had been implemented. A biomass assessment was carried out in early September prior to the early harvest date.

Prior to treatment in 2001 a mean overall weed count of 18 plants/m^2 was recorded. Weeds were assessed prior to herbicide treatments and thus assessed on different dates and hence different times after the drilling of the beet. There were a number of significant differences between weed densities pre-herbicide treatment in year 3 resulting from the treatments applied in year 1 (1998). Uneven distribution of weeds in the treatment plots and the different timing of the assessments, also contributed to the apparent differences at the pre-herbicide assessment (Table 5.3.2.2).

The main weeds showing significant differences were *P. annua*, *U. urens* and *V. arvensis.* Notably these were the weeds that were poorly controlled by the rape treatments in year 1; glufosinate had failed to control *P. annua*, the conventional treatments had not effectively control *V. arvensis* and none of the treatments had given good control of *U. urens*. In some cases, responses were independent of year 1 and significant effects were recorded from year 3 treatments with the weed species *P. annua* and *C. bursa pastoris*, prior to herbicide treatment (data not shown). These were probably due to the differences in the dates of assessment.

Table 5.3.2.2. NIAB Rotation 3: Impact of year 1 treatments on the weeds present pre-herbicide treatment in spring 2001 (year 3). (Log10 transformed weed density plants/m^2)

Weed species	conventional	glufosinate	glyphosate	Statistical significance	Standard error of difference between means
B. napus	0.461	0.563	0.214	**	0.0889
C. bursa- pastoris	0.192	0.302	0.311	NS	0.125
P. annua	0.542	0.950	0.463	**	0.128
U. urens	0.342	0.553	0.418	**	0.0502
V. arvensis	0.502	0.221	0.084	*	0.172
Total weeds	1.255	1.334	1.088	***	0.0589

In the assessments after the application of the herbicide treatments the factorial analysis showed which year 1 and 3 treatments were affecting weed densities in year 3 (Table 5.3.2.3). Significantly more *P. annua, U. urens* and total weeds were present in the plots treated with glufosinate in year 1 (Table 5.3.2.2). Significance in year 3, as a result of year 1 treatments, was also demonstrated for *B. napus*, where again most plants were counted in the plots treated with glufosinate. Significant effects were detected as a result of the year 3 treatments for *U. urens* and the total number of weeds, whilst results for *P. annua* approached significance. There was an overall reduction in total weed number from 18 weeds/m^2 pre herbicide to 4 weeds/m^2 at the post herbicide assessment timing. None of the treatments controlled *U. urens* particularly well, significantly poorer control from the glufosinate and glyphosate treatments. Overall the weed control was significantly better on the glyphosate treated plots and lowest from the conventional treatment. (Fig. 5.3.2.3).

Table 5.3.2.3 NIAB Rotation 3: statistical significance of the year 1 treatments and the year 3 treatments on weed species density (log10 plants/m^2) post-year 3 herbicide treatment summer 2001 (weed species present throughout rotation 3)

Weed species	Treats Yr1	Yr 3	Interaction
CAPBP	NS	NS	NS
POAAN	***	NS (p = 0.070)	NS
TRIAE	NS	NS	NS
URTUR	NS	**	NS
VIOAR	NS	NS	NS
TOTAL	**	*	NS

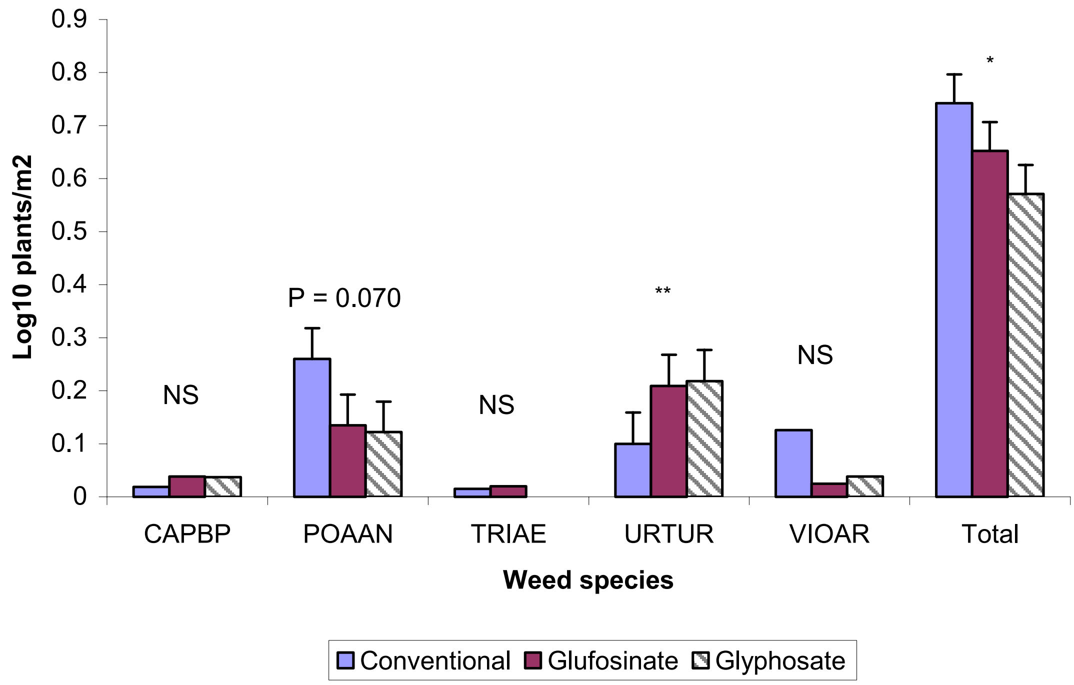


Figure 5.3.2.3 NIAB Rotation 3: Response of main weeds to the herbicides applied in year 3: post herbicide treatment (of all treatments) (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01 vertical bars = 1 x sed)

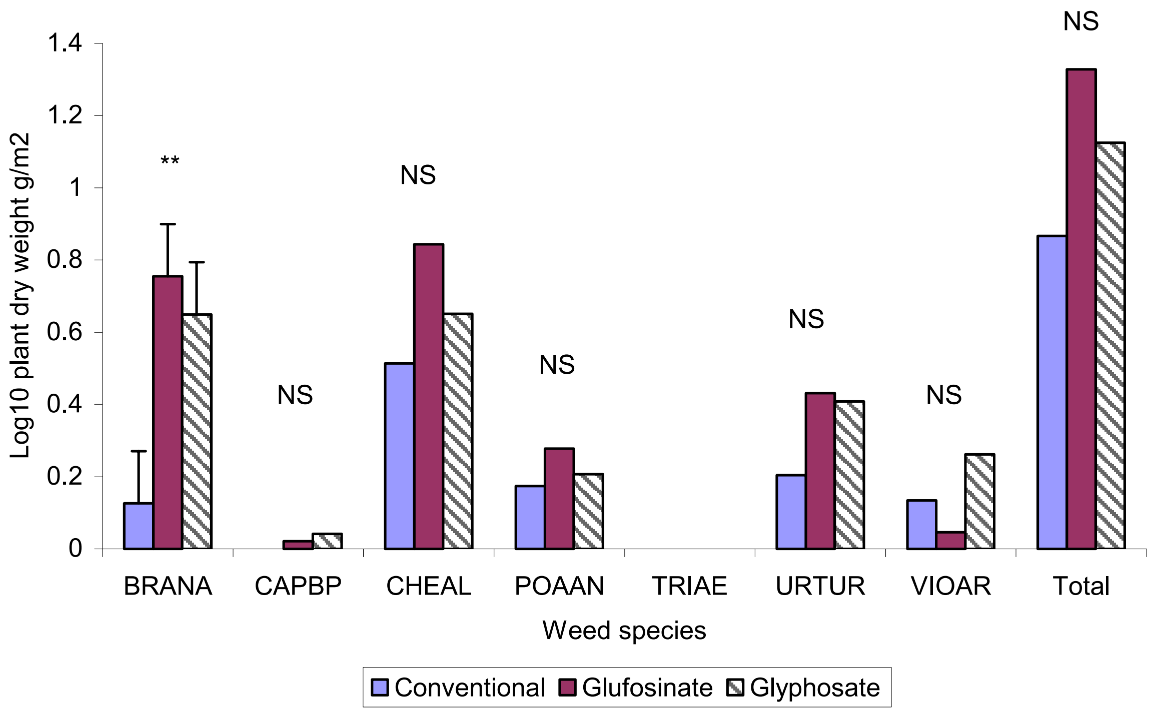


Figure 5.3.2.4 NIAB Rotation 3: Response of weeds to the herbicides applied in year 3: weed biomass assessment in late summer (NS = no significant effect of treatment; stars = significance **p<0.01, vertical bars = 1 x sed)

Weed biomass was assessed in early September 2001 There was an overall mean of 15 g/m^2. In contrast to the post-herbicide weed density assessment the Year 3 conventional treatment produced the lowest weed biomass, with the glufosinate and glyphosate producing the most (Fig 5.3.2.4). This was partly due to significantly higher quantities of *B. napus* in the glufosinate and glyphosate treatments compared to the conventional treatment ($p<0.01$), despite the addition of metamitron to the herbicide treatments to control the herbicide tolerant volunteer rape present in the plots to be treated with glyphosate and glufosinate. There was also late flush of weeds including *B. napus* in all plots. However, these apparent differences were not statistically significant. *C. album* was the most abundant weed at this harvest but no significant differences due to the treatments were apparent. No effects on weed biomass from the Year 1 treatments could be detected.

Sugar beet yield

The sugar beet crop was harvested early, on 24 September 2001, due to restrictions imposed by British Sugar. Yields varied between 34 tonnes/ha and 42 tonnes/ha with the highest yield being recorded on the conventional variety plots. There were no significant differences between varieties in either overall yield or sugar yield (Fig. 5.3.2.5).

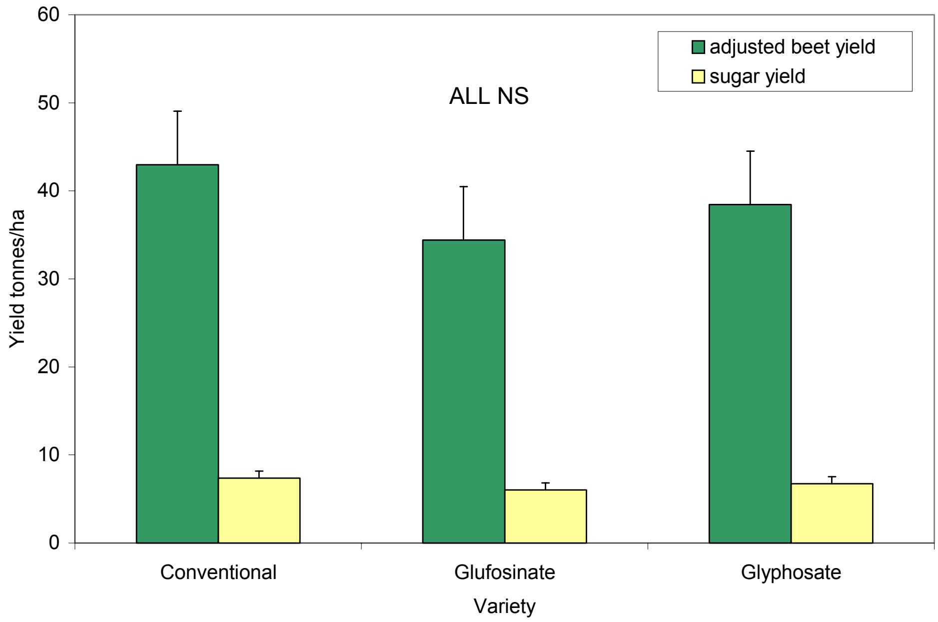


Figure 5.3.2.5. NIAB Rotation 3 : adjusted beet yield and sugar yield from sugar beet varieties grown in year 3, harvested September 2001. (vertical bars = 1 x sed).

Year 4 - winter wheat

The plots were treated uniformly in year 4, receiving a standard weed control programme (Table 10.2.5). Weed densities were relatively low in autumn 2001, the mean plant density across all treatments was 107 plants/m^2.

The most frequently occurring weeds were *P. annua, B. napus, C. bursa-pastoris*, *S. media*, *U. urens*, *Veronica* spp. and *V. arvensis*. There were no significant differences in weed densities between plots as a result of treatments in the sugar beet in the previous year. There were very low densities of weeds surviving in the following spring and across all plots the overall mean density was 0.2 plants/m^2. The main weeds present at the spring weed assessment were *V. arvensis* and *Polygonum aviculare* although both weeds were present at less than 1 plant/m^2. No significant effects from either of the two previous sets of treatments were detected.

Very low weed biomass was recorded in the summer of 2002, an overall mean of 0.13 g/m^2 and no significant differences between the former sugar beet or oilseed rape treatments were detected. The only recorded weed at the summer biomass assessment was *G. aparine*.

Conclusions - NIAB

In the year 1 oilseed rape, highest numbers of weeds were found in the glufosinate and conventionally treated plots with significantly higher plant density and biomass of *P. annua* (annual meadow-grass) and *T. aestivum* (wheat volunteers). Least weed numbers were found in the glyphosate treated plots. These results were similar to those found in NIAB rotation 1, year 1 grown in the same year, though the experiments were located in different fields.

Rotation 3 had a high population of *U. urens* (annual nettle) which none of the treatments were particularly effective in controlling, due to the protracted period over which it germinates, allowing plants to avoid treatment. *U. urens* has also been previously noted as being a less sensitive weed to treatment with glufosinate in herbicide tolerant maize (Read & Ball, 1999). There appeared to be little carry over effect of the first year's herbicide treatments into the wheat grown in the second or fourth years and overall weed density was very low.

In the sugar beet, some effects were noted from the year 1 treatments, as weed infestations prior to the year 3 treatments tended to be higher on the year 1 glufosinate treated plots. In early summer significant differences between treatments were small, but glufosinate and glyphosate tended to give higher levels of weed control for most weeds when compared with the conventional treatments, an exception being *U. urens*. However, in the biomass assessments before harvest, there were indications that the glufosinate and glyphosate treatments gave the highest weed biomass. This was partly due to a higher biomass of *Brassica napus* (oilseed rape), mainly due to late emergence and avoidance of treatment. *U. urens* and *C. album* were also common on all plots. There was no indication that weed infestations affected yields or sugar content of the beet.

There are a number of possible explanations for this switch in relative performance; the post-emergence based conventional herbicide programme consisted of 3 applications of 5 different active ingredients in total. The residual action of metamitron and the combinations of subsequent herbicides may have given more effective control of weeds with protracted germination periods. The efficacy of the later conventional sprays was compromised due to large growth stages of weeds, a steerage hoe was used to remove weed growth in the conventional plots at the end of May 2001 due to the high density of *U. urens* (annual nettle) *P. aviculare* (knotgrass) and *V. hederifolia* (ivy-leafed speedwell) prior to the final application of desmedipham + phenmedipham and triflusulfuron-methyl on 7 June 2001. This combination of a more intensive conventional herbicide programme and mechanical weeding later in the season contributed to the lower biomass sampled in these plots, compared with the GM-linked herbicide treatments.

There appeared to be no major interactions between the year 1 and year 3 herbicide treatments. The weed densities in the wheat crop in the final year showed no differences due to the treatments in previous years, partly due to very effective weed control and consequent low weed numbers.

As in Broom's Barn (Fig. 5.3.1.11) fewest weeds in mid summer were present in the winter wheat crops grown in years 2 and 4, than in the oilseed rape and beet crops. Mean weights were 31, 0.2, 15 and 0.1 g/m^2 in years 1 to 4, respectively.

5.3.3 Morley - Rotation 3

The main weeds to occur in Rotation 3 at Morley were *Lamium purpureum* (LAMPU - red dead nettle), *Fallopia convolvulus* (*Polygonum convolvulus* POLCO - black bindweed, *Poa annua* (POAAN - annual meadow-grass), *Veronica hederifolia* (VERHE - ivy leaved speedwell), *Viola arvensis* (VIOAR - field pansy).

Year 1 - oilseed rape

Four herbicide treatments were applied to the oilseed rape in the autumn of 1998 (Table 4.3.2). The conventional herbicide (metazachlor) was applied pre-emergence of the weeds to one set of plots and post emergence (metazachlor + benazolin + clopyralid) to the second set of conventional plots. The main weeds present in the post emergence treatments are shown in Table 5.3.3.1. There were significant differences between the weed densities on plots prior to treatment; however, this was attributed to the fact that a count was made on the pre-emergence conventional treatment where weeds had emerged at very low density. Rainfall in the evening after application of pre-emergence metazachlor was ideal for activity of this herbicide.

Table 5.3.3.1 Density of the major weeds present in rotation 3 prior to treatment in autumn 1998 (on post emergence treatments only)

Species	Mean weed density in autumn 1999 (plants/m^2)
Lamium purpureum	18
Poa annua	76
Veronica hederifolia	3
Viola arvensis	3
Total weeds	106

Following herbicide application, significant differences between treatments were detected the following spring. The conventional pre-emergence treatment gave significantly better control of *Poa annua* and *L. purpureum* and gave the best overall weed control (Fig. 5.3.3.1). The glufosinate treatment controlled *P. annua* the least effectively and gave the poorest weed control overall. A weed biomass assessment made in late summer showed no significant treatment differences apart from *P. annua*, where the conventional was most effective. There was a suggestion that the pre-emergence conventional treatment gave the most efficient weed control (Fig. 5.3.3.2).

The imazamox tolerant variety gave a significantly lower yield, there were no major differences in yield between conventional, glyphosate and glufosinate tolerant varieties. One plot of the glyphosate-tolerant rape was thinned due to water-logging of the soil in one low lying area of the field, but this did not adversely affect final yield since this was the highest-yielding plot of the trial.

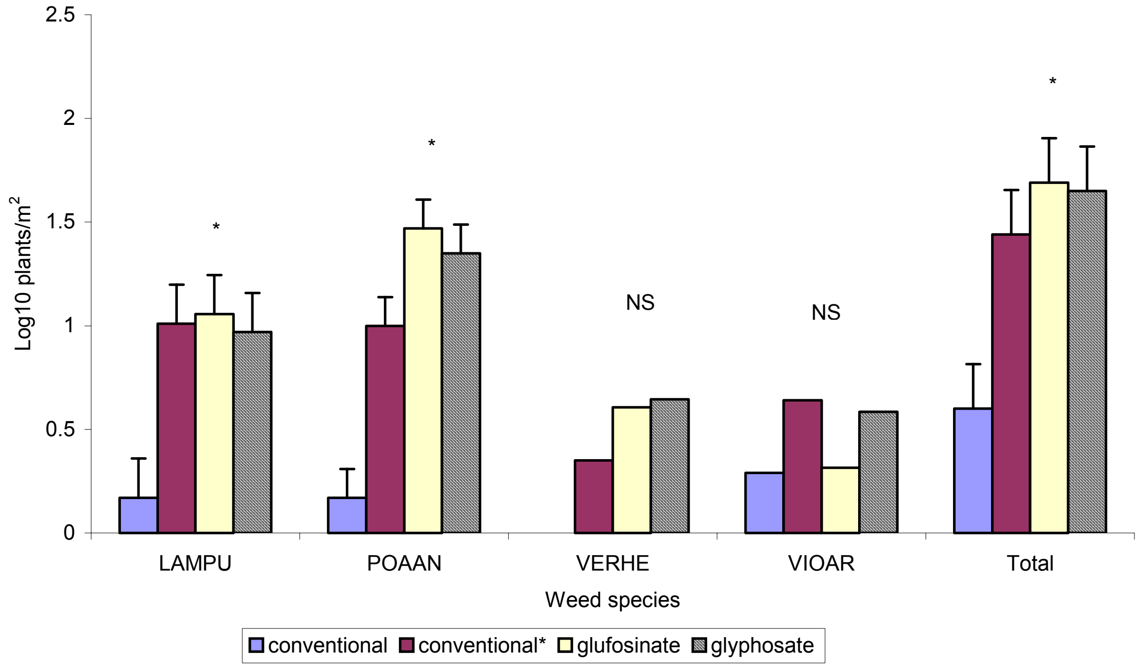


Figure 5.3.3.1 Morley rotation 3: Response of weeds in year 1 to the herbicides applied in the autumn : spring assessment of weed density (NS = no significant effect of treatment; stars = significance *p<0.05, vertical bars = 1 x sed)

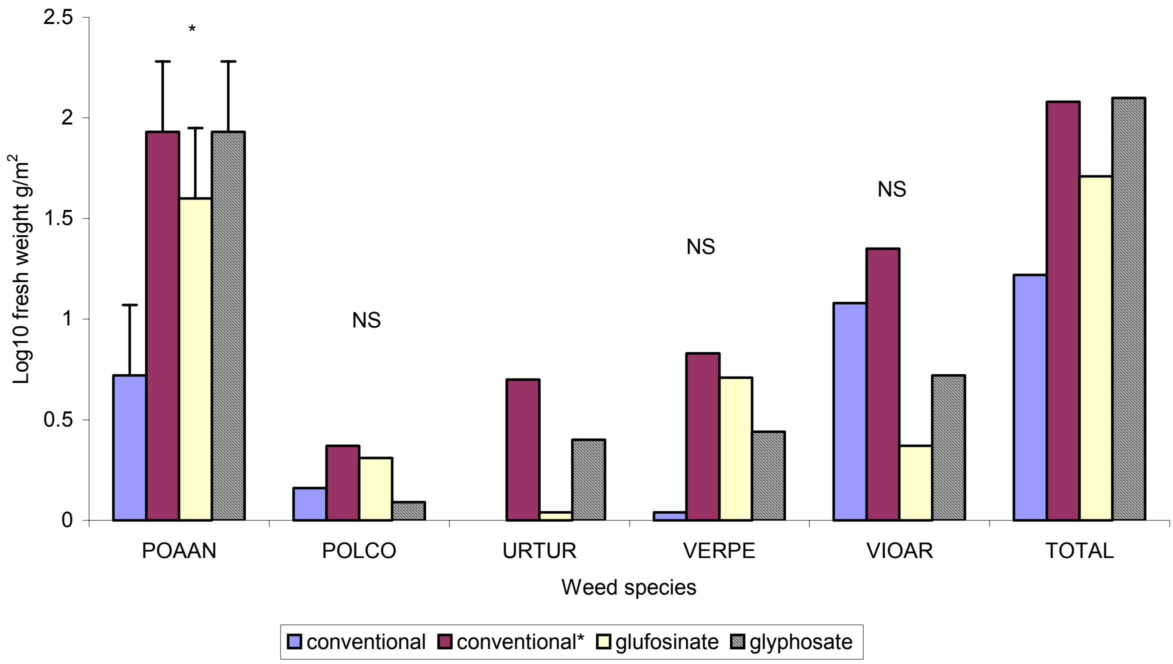


Figure 5.3.3.2 Morley rotation 3: Response of weeds in year 1 to the herbicides applied in the autumn : weed biomass assessment in late summer (biomass recorded as fresh weight). (NS = no significant effect of treatment; stars = significance *p<0.05, vertical bars = 1 x sed)

Year 2 - winter wheat

In year 2 the plots were treated uniformly with a standard pre-emergence herbicide programme (Table 10.2.7). In spring 2000, the weed count showed that the main weed was *Viola arvensis* (62 plants/m^2) and the overall mean weed density was 107 plants/m^2. No significant effects from the year 1 oilseed rape treatments were detected (Fig 5.3.3.3).

A biomass assessment in summer showed that a follow up herbicide treatment in the spring (metsulfuron-methyl + mecoprop-P) had been successful, with a total weed biomass of 5.8 g/m^2, consisting almost entirely of *Poa annua*. There were no significant differences between the former rape treatments.

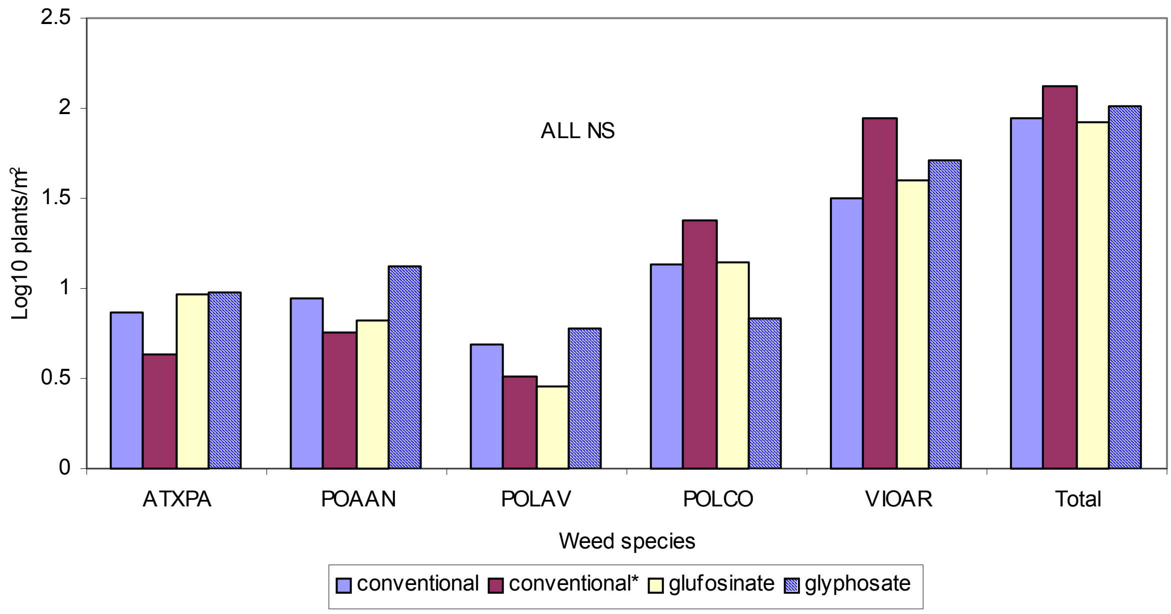


Figure 5.3.3.3. Morley rotation 3: Response of weeds in year 2 to the herbicides applied in year 2. : spring assessment of weed density (no significant effect of treatments at p<0.05)

Year 3 – sugar beet

Three herbicide treatments were used in the sugar beet crop, conventional, glufosinate and glyphosate, details of each treatment are shown in Table 4.3.2. In plots where similar beet treatments followed rape treatments and herbicide tolerant rape volunteers were anticipated, the glufosinate and glyphosate treatments were tank mixed with metamitron to control tolerant rape volunteers. Weed control in the beet plots was entirely due to the herbicides applied. No mechanical activities such as tractor-hoeing were undertaken since the field was not populated with weed beet.

Weed assessments were carried out pre-herbicide treatment, post-herbicide treatment after the final herbicide treatment. A late summer biomass assessment of weeds growing in the crop was also made. Prior to treatment in 2001 an overall mean weed count of 98 plants/m^2 was recorded. Weeds were assessed prior to herbicide applications in the spring, there were no significant differences between treatments.

The factorial analysis showed which treatments were affecting weed densities in year 3 post herbicide treatment (Table 5.3.3.2). There was an overall reduction in weed numbers to 30 plants/m^2 at the post herbicide timing. Significantly higher numbers of *B. napus* and *L. purpureum* were recorded in the glufosinate treated plots (see Plate 5.3.3.1). Overall, the weed control was significantly better on the glyphosate treated plots and weed counts were the highest in the glufosinate treatment (Fig. 5.3.3.4). The high numbers of volunteer oilseed rape recorded in the glufosinate and to a lesser extent the glyphosate plots was attributed to the failure of the tank mix (metamitron) to control the tolerant volunteers.

Table 5.3.3.2. Morley rotation 3: statistical significance of the year 1 treatments and the year 3 treatments on weed density (log10 plants /m^2) post year 3 herbicide treatment summer 2001

Weed species	Treats Yr1	Treats Yr3	Interaction
Brassica napus	n/a	*	**
Lamium purpureum	*	**	NS
Polygonum convolvulus	NS	*	NS
Viola arvensis	NS	**	NS
Total	**	***	**

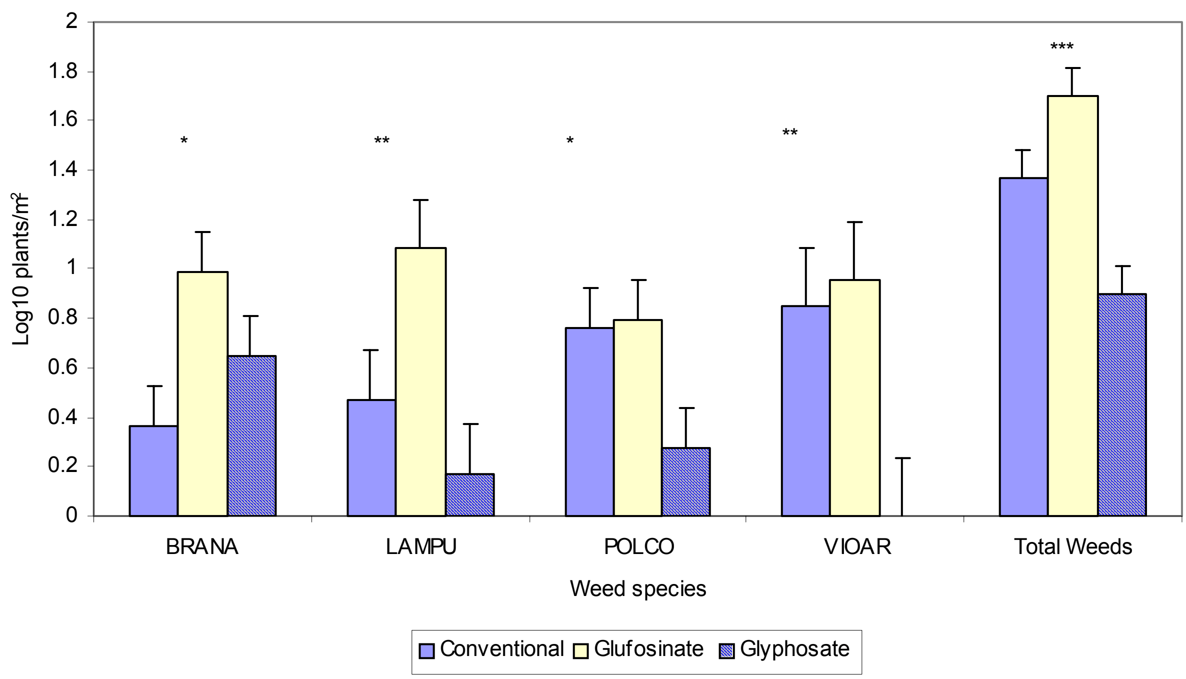


Figure 5.3.3.4. Morley rotation 3: Response of weeds to the herbicides applied in year 3.: post herbicide assessment (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

Weed biomass was assessed in early August 2001, there was an overall weed biomass (fresh weight) of 266 g/m^2. In common with the post herbicide weed counts the glyphosate treatment performed significantly better overall (Fig. 5.3.3.5).

The conventional treatment was significantly better in controlling most of the main weed species compared with the glufosinate treatment (see Plate 5.3.3.1). Higher quantities of *B. napus* and *L purpureum* were recorded in the glufosinate plots, reflecting the higher densities recorded at the post herbicide assessment. The conventional treatment produced significantly more *P. convolvulus* than other treatments.

Beet growth in all the plots was typical of beet crops in the area with canopy completion during July. The highest-yielding beet was the conventionally grown beet with a herbicide programme that started with pre-emergence chloridazon followed by conventional post-emergence tank-mixtures.

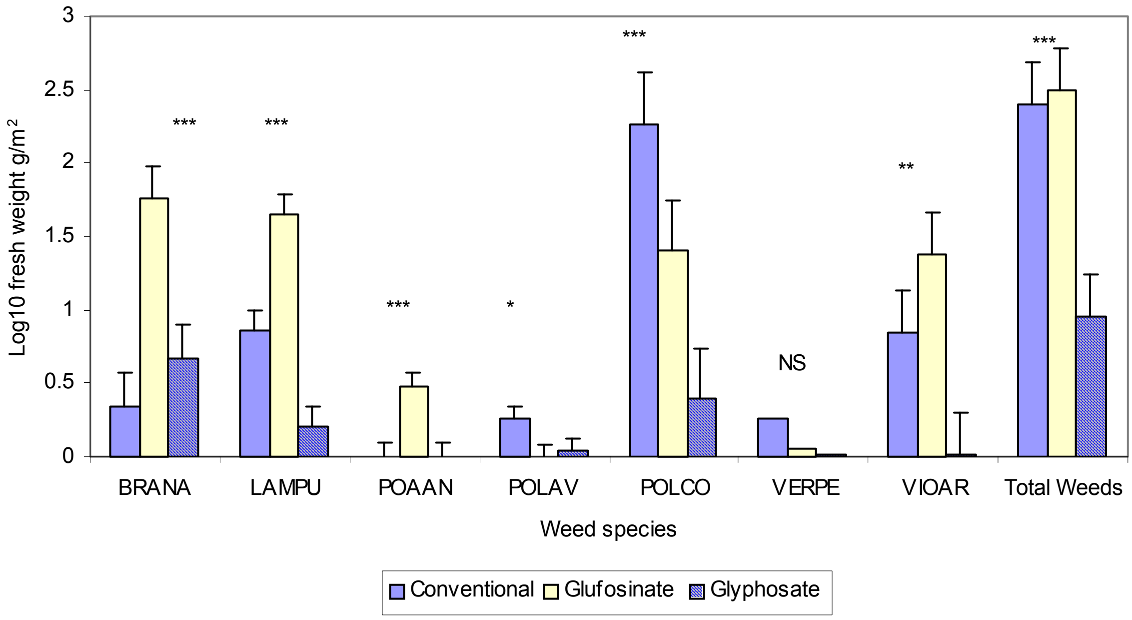


Figure 5.3.3.5 Morley rotation 3: Response of weeds to the herbicides applied in year 3. Weed biomass assessment in late summer (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, ***p<0.001, vertical bars = 1 x sed)

Sugar beet yields

Yields were highest on the glufosinate plots and were lowest on the glyphosate plots. This yield response does not seem top be linked to the levels of surviving weeds shown in the previous figure, as least weeds were on the glyphosate treated plots. There was also some evidence that where glyphosate followed glyphosate and glufosinate followed glufosinate yields were marginally lower than their comparable plots with different herbicide sequences. This could have been due to a combination of the competitive effects of the volunteer rape and of the added herbicide treatments used to control them. (see Plate 5.3.3.1.) Sugar contents of the conventional beet (16.6%) was marginally lower than those of the glyphosate and glufosinate beet (17.2-17.3%).

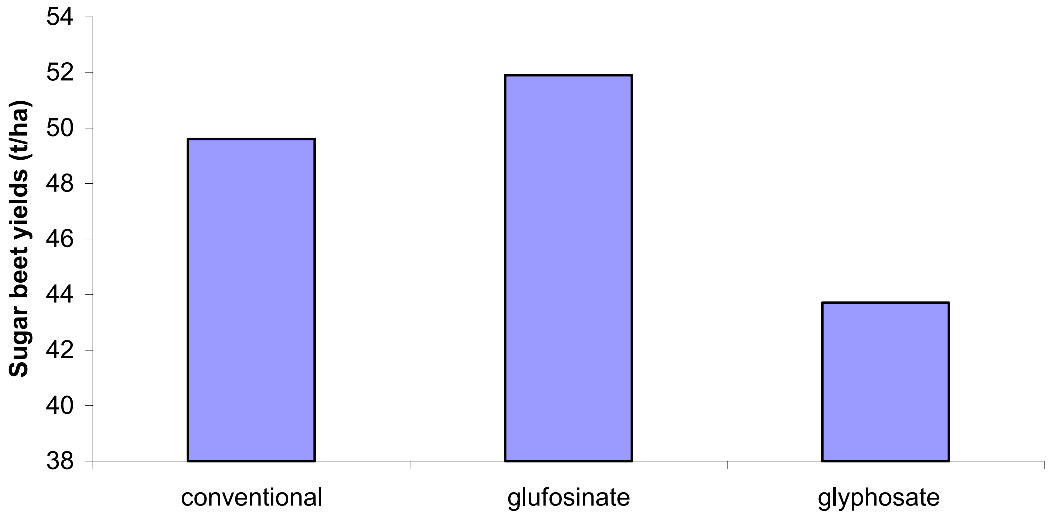


Figure 5.3.3.6 Morley rotation 3: Response of beet yields to the herbicide treatments in year 3.

Year 4 – winter wheat

The plots were treated uniformly in year 4 receiving a standard weed control programme (Table 10.2.7). Weed numbers were very low in autumn 2001 and in the following spring and were not assessed. The low weed numbers were reflected in the weed biomass results from summer 2002 where an overall mean dry weight of 0.39 g/m^2 was recorded. The main weed was *Galium aparine*, the levels were significantly higher in the former glufosinate treated plots ($p<0.001$), although the very low quantities of sampled suggests the agronomic significance of the weed was low.

Conclusions - Morley

The pre-emergence conventional treatment (metazachlor) gave significantly better weed control than the other treatments in the oilseed rape crop in year 1. The performance of the pre-emergence treatment was enhanced by optimum soil and weather conditions at the time of application. Similar levels of weed control were recorded for the glufosinate, glyphosate and post-emergence conventional treatments. The weed control programmes based on pre-emergence treatments in the winter wheat crops in years 2 and 4 gave successful weed control, shown by the very low summer weed biomass results.

In year 3, beet growth in all the plots was typical of beet crops in the area with canopy completion during July. The highest-yielding beet was the conventionally grown beet with a herbicide programme that started with pre-emergence chloridazon followed by conventional post-emergence tank-mixtures. The glyphosate treatment performed significantly better overall, having the lowest post herbicide total weed counts and biomass results. While glyphosate, and to a lesser extent glufosinate, can be used to control large weeds, late removal might compromise yield potential.

Plate 5.3.3.1. Morley rotation 3, year 3. Oilseed rape volunteers and weeds in glufosinate treated beet in year 3, following glufosinate tolerant rape in year 1.

The post emergence weed counts and biomass results showed some apparent differences in the sensitivity of weeds to the different herbicide treatments, with the glufosinate treatment being notably weaker on *L. purpureum* and *B. napus*. The high numbers of volunteer oilseed rape recorded in the glufosinate and to a lesser extent in the glyphosate plots was attributed to the failure of the tank mix (metamitron) to control the tolerant volunteers arising from the oilseed rape crop in year 1. This may have been due to the tank mix being applied after the optimum growth stage for the application of metamitron, but at the optimal timing for glufosinate and glyphosate. This problem was most apparent where glyphosate was applied to glyphosate resistant volunteer rape and similarly glufosinate resistant rape treated with glufosinate. The conventional treatment gave less efficient control of *P. convolulus* and *P. aviculare*. Both conventional and glufosinate treatments did not fully control *V. arvensis*, shown by the post emergence weed count.

Overall weed infestations in summer were highest in the sugar beet and lowest in the cereals.

5.3.4 Weed Seedbank in Rotation 3

5.3.4.1 Morley

Assessments of the seed banks were confused by apparently high levels of *B. napus* seed (or a related member of the *Brassicaceae* such as *S. arvensis*) recorded in samples taken before the commencement of the field experiments. Since no *B. napus* had been grown at the site in previous years, and S. *arvensis* was not recorded as being present on this site no explanation for this was forthcoming. It was therefore decided not to use seed bank data from this experiment.

5.3.4.2 NIAB

Year 1

At NIAB in autumn 1998 13 weed species were identified of which 6 main species dominated the seedbank. This contrasts with the field at the same site sown with Rotation 1, where there were few weed species and the seedbank was generally quite low (Section 5.1.5). The most abundant species were *U. urens* (URTUR), *C. album* (CHEAL), *P. annua* (POAAN), *P. aviculare* (POLAV), *C. bursa pastoris* (CAPBP), *Sonchus* species (SONsp) which comprised of both *Sonchus asper* and *Sonchus oleraceus* (Fig. 5.3.4.1).

Seed levels varied across plots and levels of *P. aviculare* were particularly variable with low densities occurring in the plots to be treated with glufosinate, although no significant differences were detected. *B. napus* seeds were recorded only in the plots to be treated with glufosinate (403 seeds/m^2). The overall mean number of seeds across all plots was 14,453 seeds/m^2.

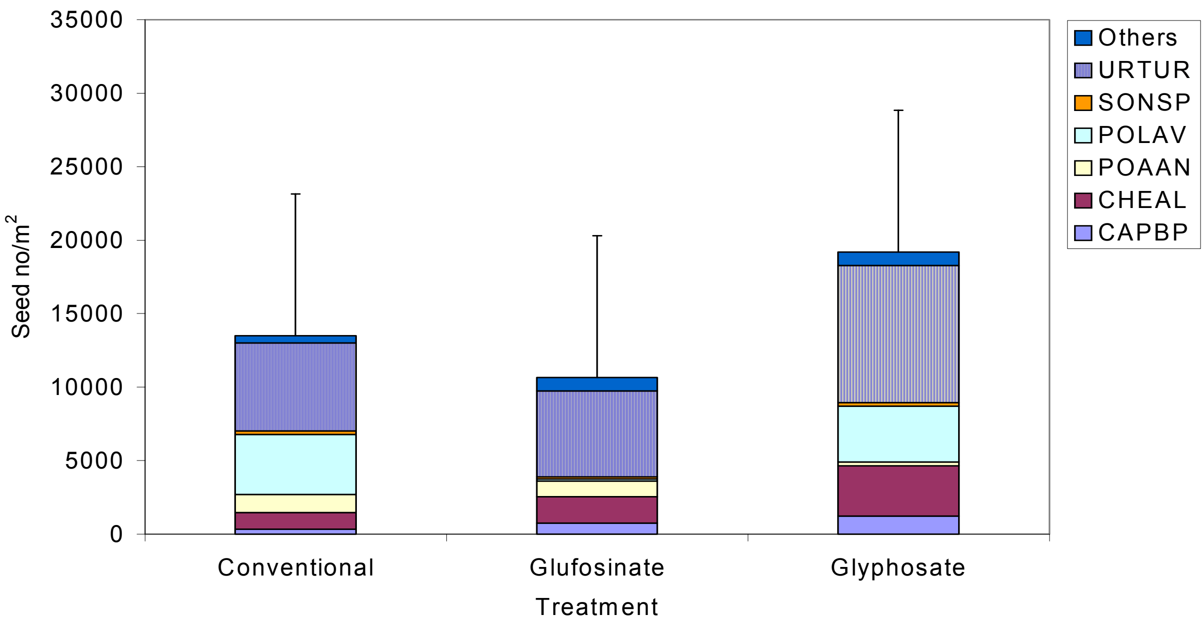


Figure 5.3.4.1 NIAB Rotation 3: Seed numbers/m^2 in the seedbank in autumn 1998 prior to the application of herbicide treatments. (vertical bars = sed of the total weed number)

Year 4

The seedbank sampled during the fourth year could have been influenced by the winter rape treatments applied in year 1 and the sugar beet treatments applied in year 3. The efficient weed control in years 2 and 4 were unlikely to have greatly influenced the seedbank. There was an increase in the total seedbank from 14,453 seeds/m^2 in year 1 to 18,974 seeds/m^2 in year 4. A substantial density of *B. napus* seeds was recorded in all plots in year 4 with an overall mean of 437 seeds/m^2, which is similar to the density recorded in year 1 in the glufosinate treatment (403 seeds/m^2).

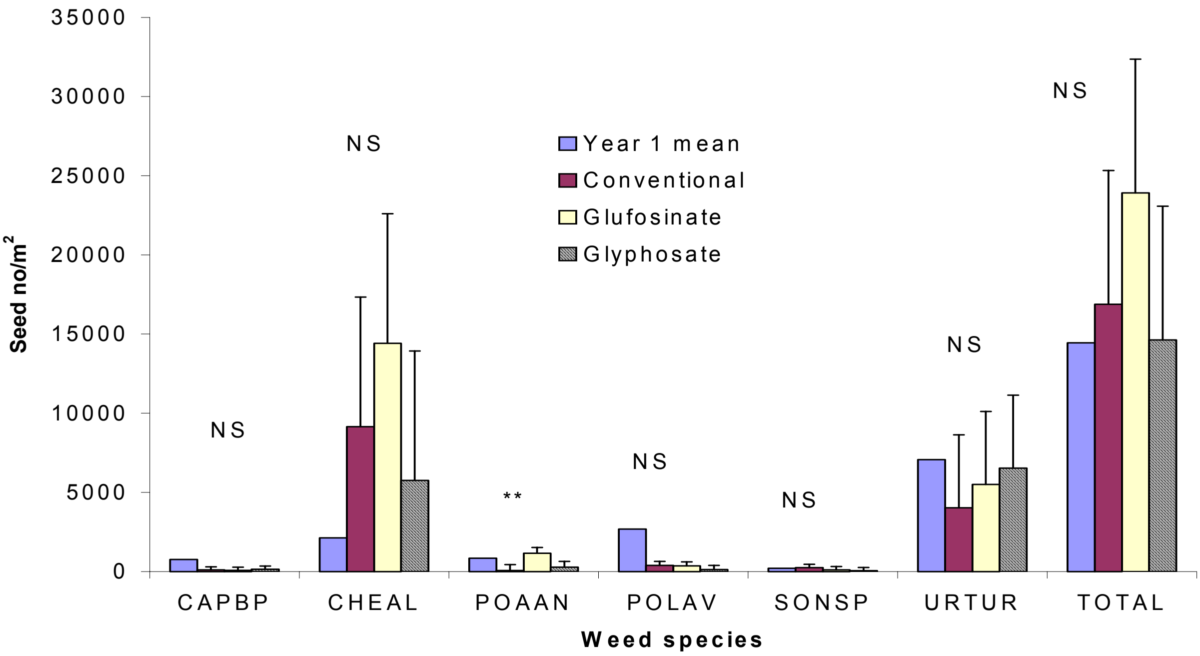


Figure 5.3.4.2 NIAB Seedbank in year 4 following treatment in year 1 and year 3, mean seed density from year 1 given as a comparison - Effect of year 1 treatments (NS = no significant effect of treatment; stars = significance **p<0.01, vertical bars = 1 x sed)

C. album, P. aviculare and *U. urens* dominated the seedbank in years 1 and 4. Although there was high variability in the data, significant differences were detected in year 4 as a result of treatments applied in year 1, year 3 and due to the interaction between year 1 and year 3 treatments.

Significant effects as a result of the year 3 treatments were shown for *P. aviculare,* and as a result of both year 1 and year 3 treatments for *P. annua* (Figs. 5.3.4.2 & 5.3.4.3). In year 1 significantly higher levels of *P. annua* were recorded in the weed biomass samples from the glufosinate treatment, in year 3 there was some indication that higher biomass of *P. annua* was recorded in the glufosinate treatment (Figs. 5.3.2.2 and 5.3.2.4).

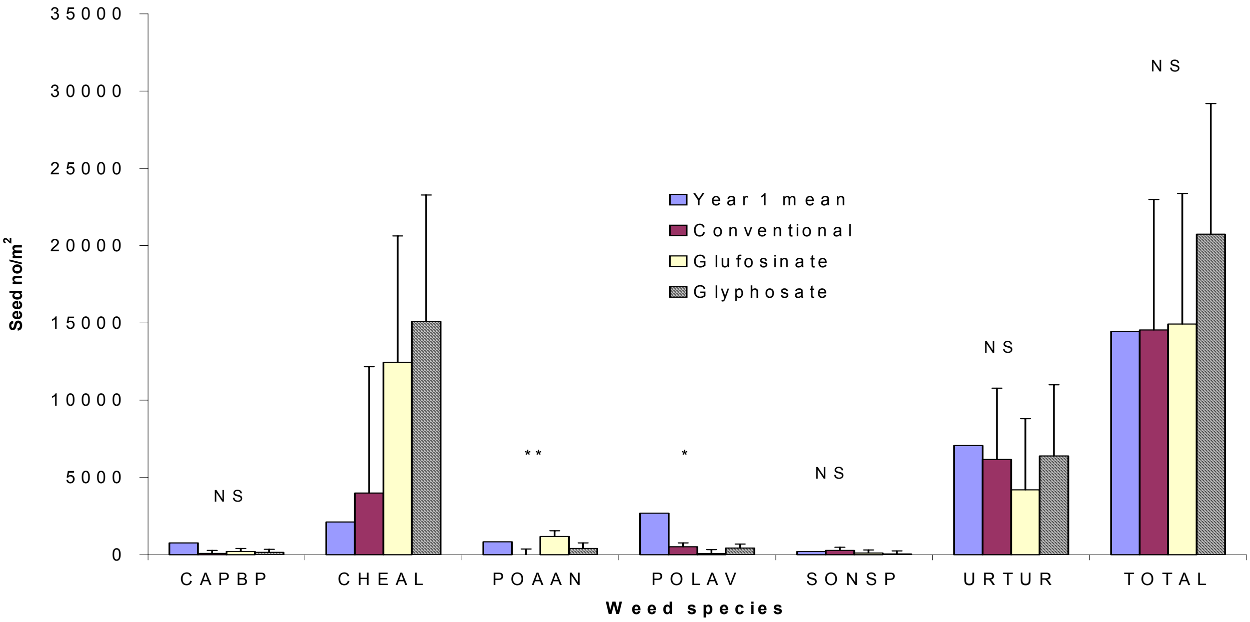


Figure 5.3.4.3 NIAB Seedbank in year 4 following treatment in year 1 and year 3, mean seed density from year 1 given as a comparison - Effect of year 3 treatments (NS = no significant effect of treatment; stars = significance *p<0.05, **p<0.01, vertical bars = 1 x sed)

A significant interaction between year 1 and year 3 treatments was shown for *P. annua* (p=0.016) principally as a result of higher density recorded in the glufosinate treatment applied in years 1 and 3 (Figure 5.3.4.4). A significant interaction was also shown for total weed numbers (p=0.02), where most seeds were found on the glufosinate treated plots (Figure 5.3.4.5). This higher total density of seeds is probably linked to the high numbers of *P. annua* recorded in these plots.

The factorial analysis of year 1 on year 3 treatments also showed effects approaching significance for *C. album* (p=0.073). The log10 transformed data analysis showed some further significant main effects and interactions, between year 1 and year 3 treatments, for both major and minor weed species present (Table 5.3.4.1).

Table 5.3.4.1 NIAB Rotation 3 : statistical significance of the year 1 treatments and year 3 treatments on the weed seedbank in year 4 (Spring 2002) (Log10 seeds/m^2)

Weed species	Year 1 treatment	Year 3 treatment	Interaction
Brassica napus	NS	NS	*
Chenopodium album	NS	NS	*
Sonchus sp.	NS	*	NS
Urtica urens	NS	NS	**
Veronica hederifolia	*	*	NS
Viola arvensis	NS	NS	p=0.059
Total weeds	NS	NS	*

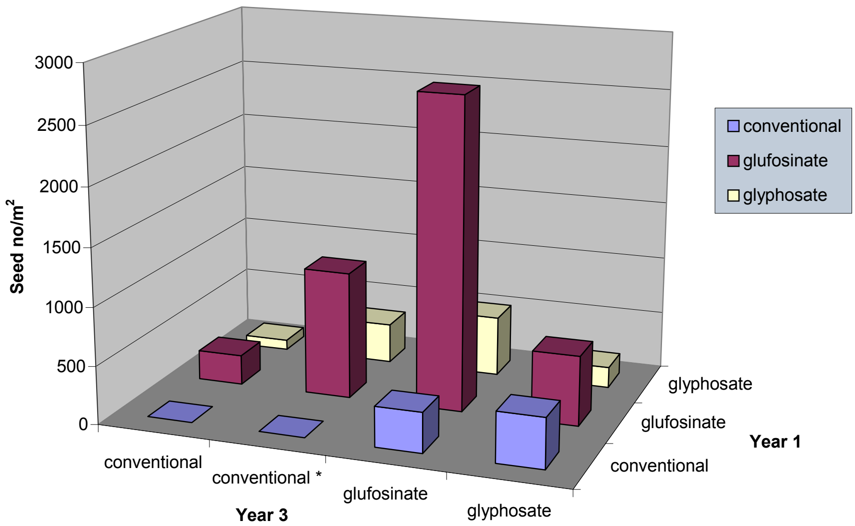


Figure 5.3.4.4 NIAB, seed bank Rotation 3: The effect of year 1 and year 3 treatments on the number of *Poa annua* seeds/m^2 in year 4 (sed = 366.1)

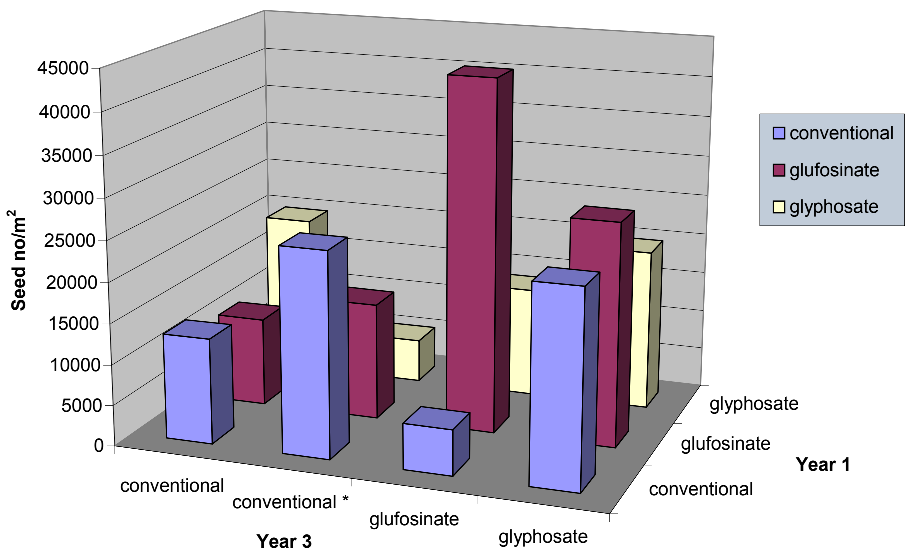


Figure 5.3.4.5 NIAB, seed bank in Rotation 3 : The effect of year 1 and year 3 treatments on the total number of weed seeds/m^2 in year 4 (sed = 8450.7)

The uneven distribution of weeds in the initial seed banks (before treatments were applied) and the removal of imidazolinone treated plots from the analysis of year 1, has distorted the analysis so that there appear to be significant interactions when data are expressed as log10. In fact, because of the high variability, there is no particular pattern for most weeds. Only *P. annua* seems to present a consistent pattern, with higher weed biomass in years 1 and 3 in glufosinate treated plots leading to higher seed returns and an increased seed bank at the end of the experiment.

5.3.4.3 Brooms Barn Rotation 3

At the outset of this experiment there were 15 species found in the seedbank. Many of these occurred only rarely. The seed bank was dominated by *C. album* (CHEAL) (Fig. 5.3.4.6). The other main species were *P. annua* (POAAN) *S. media* (STEME), *V. arvensis* (VIOAR) and a mixture of *Veronica persica* and *V. hederifolia* (VER spp). There were no obvious differences between the treatments at this stage but as the plots were rather variable the standard errors are large. Overall mean was 5416 seeds/m^2.

At the end of the experiment in year 4 the seed bank analysis showed there had been a considerable increase in the density of total seeds up to a mean of 13,460 /m^2. This was primarily due to the increase in *C. album* seeds up to a mean of 11,109 seeds/m^2. As this weed was not common in the winter cereals in years 2 and 4, nor was present in the winter rape in year 1, this increase must be mainly associated with the survival of this weed in the sugar beet grown in year 3. Weed control data (Fig 5.3.1.4) showed poor control of this weed, especially in the plots treated with conventional herbicides and glufosinate. This accords partly with the seed bank data (Fig. 5.3.4.7), as most seeds were found on the year 3 glufosinate treated plots. However, there was a stronger correlation between weed biomass (summer year 3) and the seed bank (%va = 72) (Fig. 5.3.4.8) The other species had not greatly increased their density.

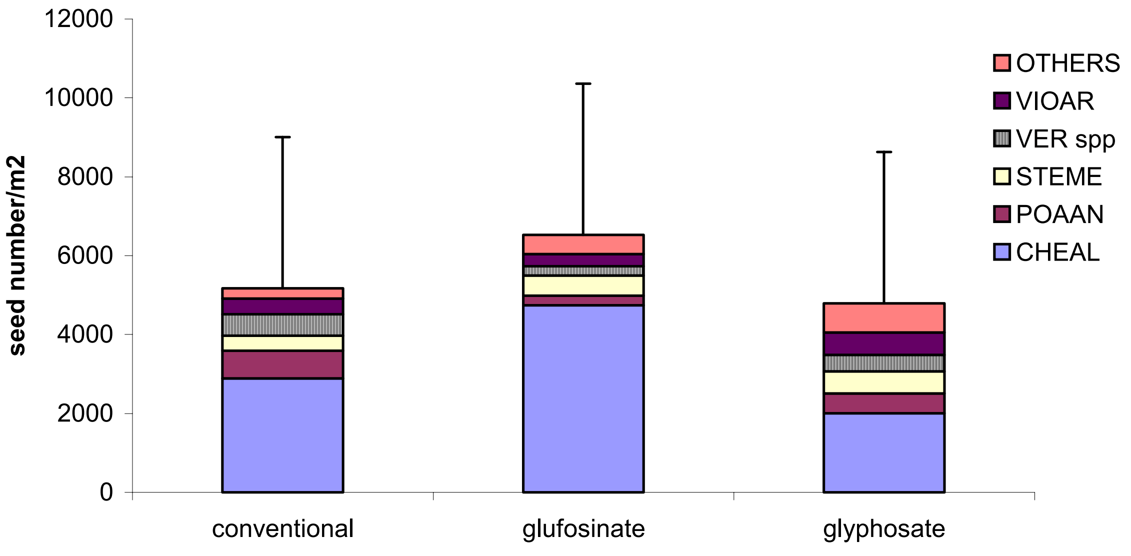
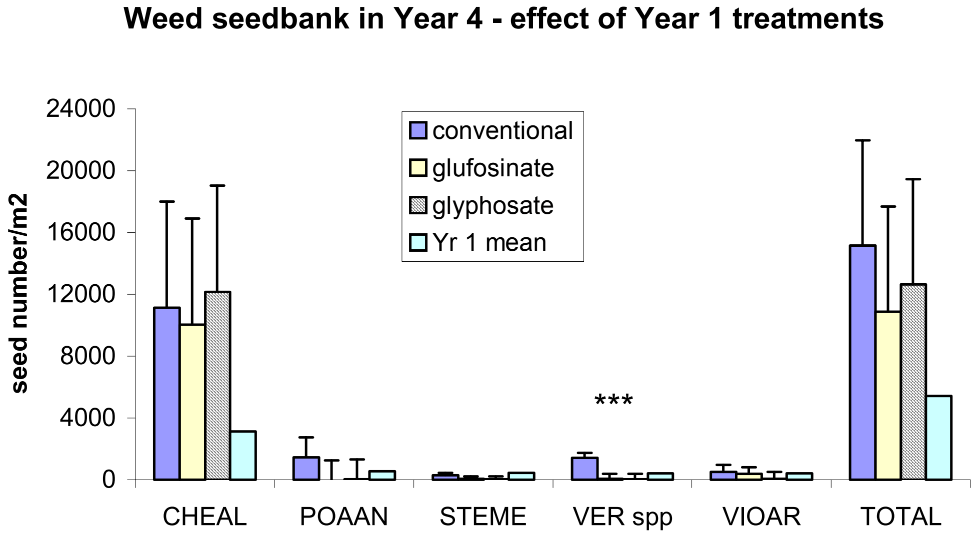


Figure 5.3.4.6 Brooms Barn rotation 3: Seed numbers in the seedbank in autumn 1998 prior to the application of herbicide treatments (vertical bars are the SEDs of the total numbers



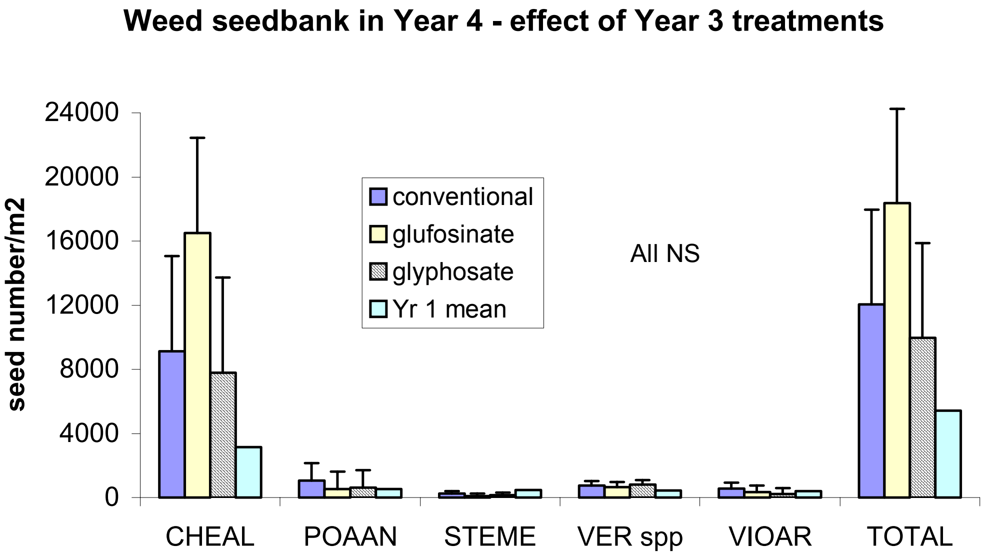


Figure 5.3.4.7. Broom's Barn rotation 3: Seed numbers in the seed bank in Year 4, following treatments in Years 1 & 3. Mean densities from year 1 given for comparison. Effects of Year 1 and year 3 treatments presented separately. (Vertical bars are SEDs)

By contrast, for *P .annua, S. media* and the *Veronica* species there was evidence of an effect of the treatments in year 1. Most weed seeds were found on the plots treated with the year 1 conventional herbicide and these differences were only statistically significant for *Veronica.* This accords with the weed biomass data in summer 1999 as none of these species were well controlled by the conventional treatment. As in the first year, there was considerable variability in the seed data and most differences were non-significant. Transformation of the data by Log10 failed to generate any other significances, though it did improve the distribution of the data in the analyses.

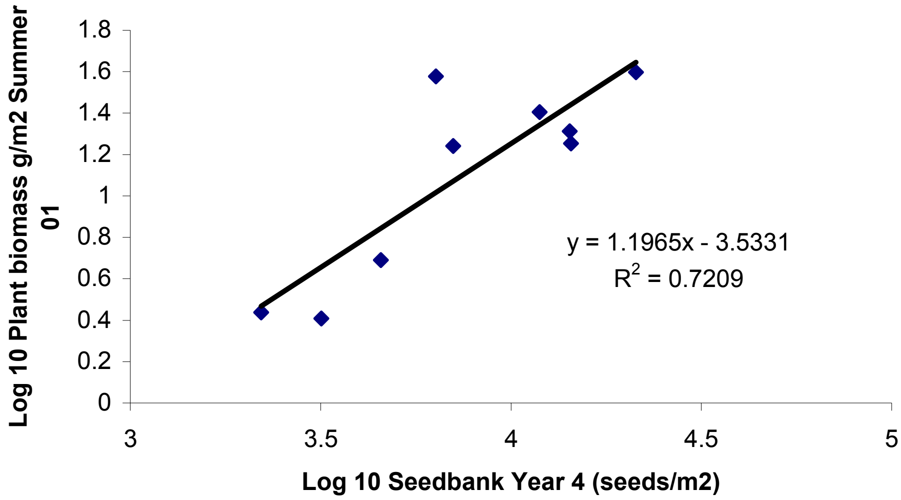


Figure 5.3.4.8. Broom's Barn rotation 3: Comparison of the *C. album* seedbank in Year 4 with the biomass of this weed present in Year 3 (data are treatment means).

5.3.5 Conclusions from Rotation 3

Rotation 3 was established to explore the impact of planting two different herbicide tolerant GM crops in quite close succession in the same rotation. All three sites sowed winter oilseed rape (WOSR) in year 1 and then sugar beet in year 3, with cereals sown in years 2 and 4.

The rotation posed several specific questions:

a) if two GM crops were grown is close succession, was there a carry over of the effects of weed control from the first to the second GM crop?
b) volunteer GM rape seeds would persist after the harvest of the GM rape and hence GMHT volunteers would be present in the GMHT beet. Would these pose problems?
c) Within the rotation was it better to retain the same herbicide resistance character in both crops or was it better to switch to a different one in the second crop?

Rotation 3 also provided supplementary data on the performance of the glyphosate and glufosinate HT beet and oilseed rape, in comparison to the conventional cultivars, to support the data from Rotations 1 and 2.

Herbicide performance on oilseed rape (WOSR)

The three sites provided some contrasting data, especially in relation to the performance of the conventional herbicides. The pre-emergence metazachlor achieved higher levels of weed control at Morley than the two HT treatments. In contrast the late application of benazolin at Broom's Barn gave much reduced levels of weed control compared with glyphosate and glufosinate. At NIAB, glyphosate was more effective than the conventional and glufosinate treatments. These results were similar in variation to those in Rotation 1, where glyphosate was most active in more site/years, as was the case in Rotation 3 at NIAB.

Herbicide performance in sugar beet

The weed control in year 3 was affected by the herbicides applied to the sugar beet, but because of the factorial arrangement of the plots, it was also possible to detect carry over effects from year 1. The carry over effect was most marked at Broom's Barn, where poor control by the conventional treatment in the first year oilseed rape was still influencing the weed flora in the third year. Carry over effects were least evident at Morley. Glyphosate treatment in beet at Morley was clearly the most effective but treatment differences were less marked at the other two sites. Interestingly, Morley was the only one of the three sites to use two applications of glyphosate.

One of the consequences of following HT WOSR with another HT crop is the management of HT volunteer WOSR. For example, where glyphosate tolerant beet was planted after glyphosate tolerant WOSR, the volunteer rape would not be controlled by the glyphosate. Consequently, metamitron was added to the herbicide treatments on the relevant glyphosate and glufosinate plots to enhance the control of the volunteer rape. This was not fully successful. Additionally, as few of the conventional beet herbicides are very effective on the anticipated volunteer rape (from both conventional and HT cultivars) triflusulfuron was added to the products applied, to enhance volunteer rape control. One further factor to emerge from this work was the variability in susceptibility of some of the weed species to the conventional, glyphosate and glufosinate treatments. Although glyphosate tended to be more effective it was especially poor on *U. urens* at NIAB and glufosinate was clearly poor on *Viola arvensis* at Morley and was not as effective as glyphosate on *F. convolvulus* at Morley and *C. album* at Brooms Barn. Such comparisons would need more extensive studies to confirm strengths and weaknesses. Such information may be extractable from the data of the Farmscale Evaluations of GM crops, which indicated that glyphosate in general was more effective than the conventional treatments (Heard et al., 2003).

Oilseed rape yields differed between the studied cultivars (Section 6) and, as in Rotation 1, there was a tendency for the imidazolinone resistant rape to be the lowest. However, this was unlikely to be linked to the performance of the herbicide treatments, as yield differences and herbicide performance did not seem to be correlated and additionally the imidazolinone tolerant rape was given similar herbicide treatments to the conventional plots. There was also little evidence that surviving weeds in the sugar beet in year 3 were affecting yields but comparisons of the different cultivars/treatments are again confounded by differences in the cultivars' intrinsic productivity. The conventional variety tended to give the highest yields, but as the HT cultivars planted were experimental lines and not fully commercial cultivars these differences should not be given much emphasis. However, they were not dramatically less competitive and often yielded as well as the full commercial varieties.

Management of volunteer oilseed rape

As outlined in the previous section, management of the volunteer rape in the beet crops was a problem, especially when it contained the same tolerance genes as the beet crop. This reflects current attitudes of sugar beet growers, to avoid growing WOSR in the same rotation as sugar beet. The relatively recent approval of triflusulfuron does improve control of this weed, but increases costs. The numbers of WOSR seedlings seemed to be linked quite well to the seed losses recorded at harvest, emphasising the need to minimise the establishment of a seedbank of volunteer WOSR. The problems arising from HT volunteer rape can be overcome by the development of appropriate herbicide mixtures and sequences. However this results in the loss of the 'simplicity' advantage of the HT systems and increases their costs. One would conclude that it would probably be best to follow a HT rape variety with a dissimilar sugar beet one. Because of the general adequacy of glufosinate in oilseed rape the preferred sequence would be glufosinate tolerant WOSR followed by glyphosate tolerant beet.

Overall levels of weed control tended to be higher in the cereal components in the rotations and least in either the WOSR or beet. Weed biomass in the summer never exceeded 1 g/m^2 in the cereals but reached 40 g/m^2 in one or other of the two broad-leaved crops. This concurs with other studies which have shown the importance of broad leaved crops in maintaining weed seed banks and the role of cereals in reducing them.

Changes in the weed seedbanks

Assessments of the seedbank at the beginning and end of the project on these three experiments showed that at two sites, especially Broom's Barn, it had increased. The increase at Broom's Barn was primarily associated with the poor control of *C. album* by the conventional and glufosinate treatment in the sugar beet in year 3. The same weed species dominated the flora at NIAB but high variability in the data made it difficult to assign significant responses to the treatments. The data from Morley was not analysed due to unexplained levels of seeds of *B napus* or a related member of the *Brassicaceae* at the commencement of the study. Although it is possible to identify *B. napus* seeds and for example *S. arvensis* seeds by their physical characteristics, this is not completely reliable and the only 100% confirmation would be to germinate the seeds and identify the plants. This was not possible in this circumstance.

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5.4 Rotation 4 (Cereal undersown with rape - oilseed rape - cereal - cereal)

In year 1 of this rotation high numbers of volunteer rape seeds were broadcast prior to sowing the winter cereal crop. The intention was to establish a seedbank of the four different rape types (conventional, imidazolinone resistant, glyphosate resistant, glufosinate resistant), which would then impact on the management of the oilseed rape crop sown in year 2. However, the weather conditions when the rape seeds were broadcast was not conducive to the development of secondary dormancy (high soil moisture conditions) and most of the seeds germinated immediately, resulting in a very small seedbank (Rothamsted mean = 119 seeds/m^2, SAC = 350 seeds/m^2, NIAB = none). This low level of volunteer rape seeds at SAC and Rothamsted was swamped by the numbers of seeds shed at harvest in year 2 and did not influence the results of the behaviour of the volunteer rape seeds in subsequent years (Section 6). Consequently, Rotation 4 has been treated as an extra data set to investigate the relative performance of the four treatments (applied in year 2 - autumn 1999) and any continued effect on weed levels in the subsequent two winter cereal crops.

5.4.1 Rothamsted - Rotation 4

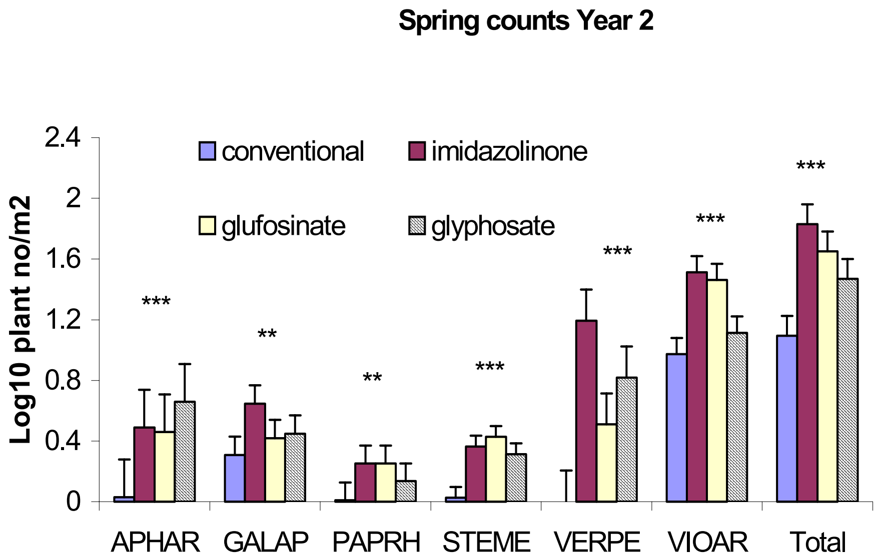
Year 1 - Winter wheat

As explained above this year was intended to establish a seedbank of volunteer rape and in other respects the crop was managed as a normal winter wheat crop. The main weeds recorded during the winter were *S. media, V. arvensis* and *A. arvensis.*

Year 2 - Oilseed rape

The main weeds present on this experiment reflected those already recorded in Rotation 1 and the flora was dominated by the same species. The main weeds recorded in autumn 1999 were *S. media, V. persica* and *V. arvensis*. *Aphanes arvensis, P. rhoeas,* and *G. aparine* were also present at mean densities above 1 plant/m^2. In autumn 1999 weed density prior to treatment was 181 plants/m^2. This assessment was based on counts in October on the imidazolinone resistant, glyphosate resistant and glufosinate resistant plots, as the ‘conventional’ treatment of trifluralin plus metazachlor and quinmerac had been applied pre-emergence and so weed numbers had been reduced.

The principle data set assessing the effectiveness of the four treatments was the counts of weed presence in early spring. This showed some surviving weeds on all plots (overall mean 44 plants/m^2), but frequently with significantly fewer plants on the conventionally treated plots. This applied to all the species mentioned above. Control of *V. arvensis* with the glufosinate treatment was not as high as with some of the other treatments (Fig 5.4.1.1). The imazamox treatment tended to result in most weeds but the treatment was only statistically significantly poorer for some species. The biomass data collected in June reflected the previous conclusions, except that the poorer control from the imidazolinone treatment was more evident (Fig. 5.4.1.2)



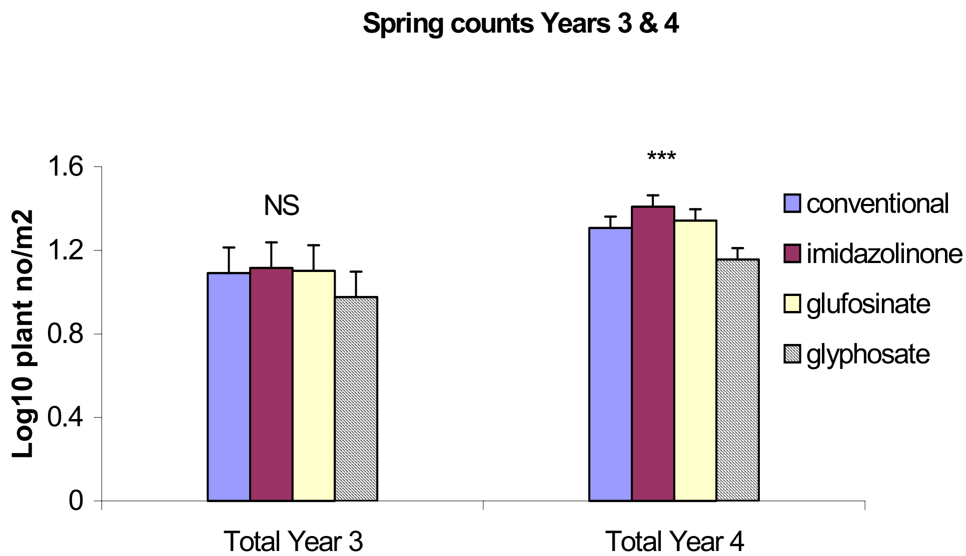


Figure 5.4.1.1 Rothamsted Rotation 4 : Response of weeds in years 2-4 to the herbicide treatments in year 2: spring assessments of weed density (NS = no significant effect of treatments: stars = significance * p<0.05, ** p<0.01, *** p<0.001, vertical bars = 1 x SED)

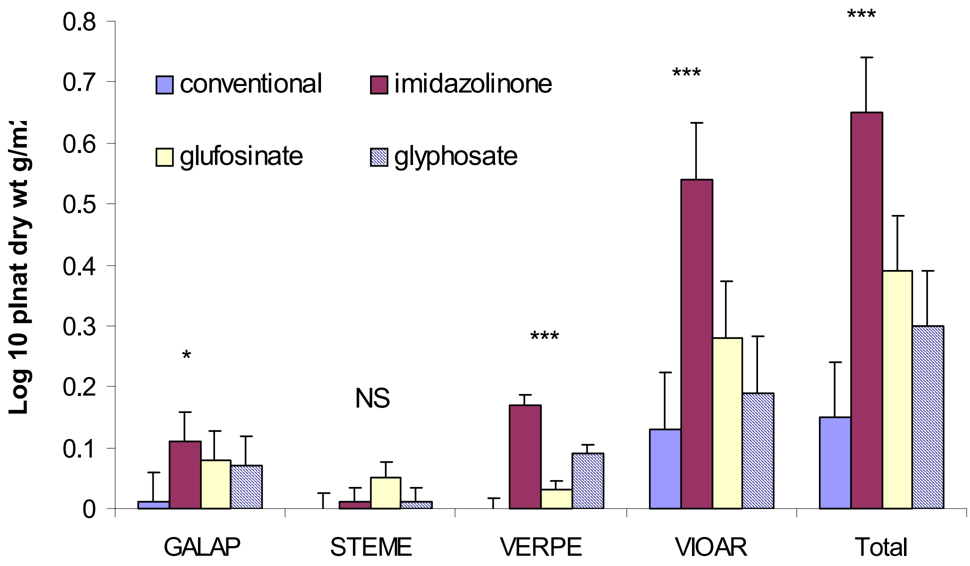


Figure 5.4.1.2 Rothamsted Rotation 4 : Response of weeds in year 2 to herbicide treatments in year 2: summer assessment of weed biomass (NS = no significant effect of treatments: stars = significance * p<0.05, ** p<0.01, *** p<0.001, vertical bars = 1 x SED)

Years 3 and 4 - Winter wheat

In the following crops of wheat few differences arising from the treatments applied in year 2 were recorded (Fig. 5.4.1.1). In year 3 weed numbers in spring were low (mean = 12 plants/m^2) and mean weed biomass in summer was less than 2 g/m^2. In the final year weed density in spring was slightly higher at 24 plants/m^2 and there were indications that most weeds were present on the plots treated with the imidazolinone herbicide and least on those treated with glyphosate, but the differences were relatively small. No significant treatment effects were evident in the following June, but appreciable quantities of *G. aparine* were present on all treatments resulting in a mean weed weight of 52 g/m^2.

Volunteer rape was present in the autumn and early spring in both years. Levels were low in year 3 (maximum of 2 plants/m^2) but were higher in year 4. In year 4 the mean level in the autumn was 11 plants/m^2, with statistically significantly more on the plots that had grown the glyphosate tolerant rape (conventional = 3.8, imidazolinone tolerant = 9.2, glyphosate resistant = 17.9, glufosinate tolerant = 11.5 plants/m^2 (sed = 2.90)). This pattern reflects the seedbank data presented in Section 6. Few were still present in the later assessments, as the herbicide treatments applied in the cereals had killed them.

Conclusions

In year 2 none of the treatments achieved total weed control. Highest weed control was achieved by the conventional treatment (trifluralin with metazachlor + quinmerac) and the imidazolinone treatment was the weakest. There was little evidence that the effects of these treatments carried over into the wheat crops sown in years 3 and 4. Weed control, had been high in both years, with the exception of the *G. aparine* in year 4.

5.4.2 Scottish Agricultural College - Rotation 4

Year 1 Winter barley

At this site winter barley was planted in year 1. The main weeds were *P. annua* and *S. media* but *V. arvensis* and *M. arvensis* were also present in appreciable numbers.

Year 2 Oilseed rape

The Conventional plots received metazachlor and benazolin + clopyralid (Butisan + Benazalox). In the autumn there was no significant difference between the treatments, weed density being 270 plants/m^2, the vast majority being *P. annua*. There were indications of the presence of higher densities of this weed on the rape plots that were imidazolinone resistant. In the following spring significant treatment effects were recorded but the most effective treatment varied with the weed species. Overall the imidazolinone herbicide (imazamox) was least effective on the *P. annua,* whilst the glyphosate and glufosinate were most effective (Fig. 5.4.2.1). As this weed predominated the same response was seen in the total weed numbers. The conventional (metazachlor and benazolin + clopyralid) was weak on the *H. vulgare* and the *V. arvensis.* Glufosinate was also less effective on *V. arvensis.* The biomass data in June 2000 (year 2) (Fig. 5.4.2.2) reflected the same trends seen in the spring weed counts (Fig. 5.4.2.1). Mean weed weight / plot was 67 g/m^2.

Year 3 Winter barley

In autumn 2000 (year 2) excessively wet conditions delayed sowing of the barley and so weed emergence was very late and few weeds emerged. Barley establishment was also very patchy in places. Consequently, no assessments were done until the summer. The major weed in the summer count of weed density was *P. annua* (Fig. 5.4.2.1). Overall mean weed density was 143 plants/m^2. Some significant differences were apparent, arising from treatments the previous year, as fewest *P. annua* and total weeds were present on the former glufosinate plots, but differences between treatments were not high.

Year 4 Winter barley

Both spring and summer assessments were done in 2002, as establishment of the crop had been less difficult in autumn 2001 (year 4). Weed levels were approximately 90 plants/m^2. Significant differences between the treatments were detected in the spring weed counts (Fig. 5.4.2.1). As in the previous year there was least *P. annua* on the glufosinate treated plots and most on those treated previously with imazamox. As *P. annua* continued to be the predominant weed these differences were also reflected in the total weed numbers. By June little weed apart from some *P. annua* survived and no statistically significant treatment effects were detected.

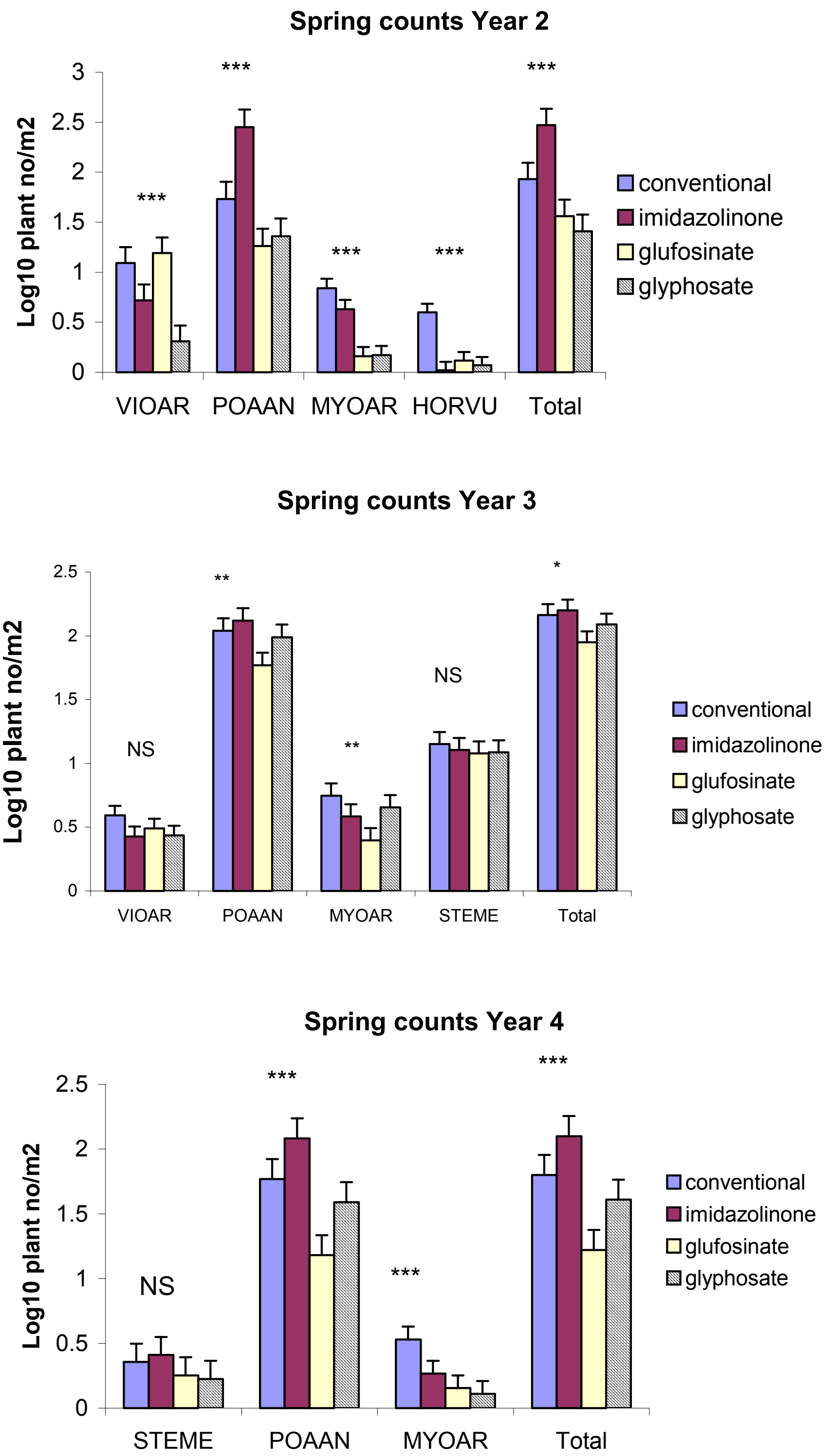


Figure 5.4.2.1 SAC Rotation 4 : Response of the major weeds in years 2, 3 and 4 to herbicide treatments applied in year 2: spring/summer assessment of weed density (NS = no significant effect of treatments: stars = significance * p<0.05, ** p<0.01, *** p<0.001, vertical bars = 1 x SED)

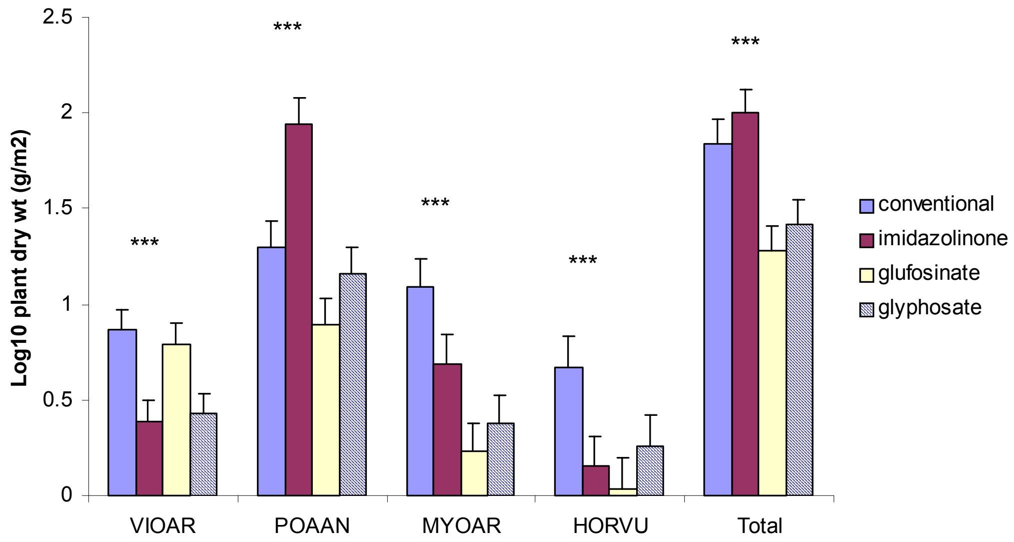


Figure 5.4.2.2 SAC Rotation 4 : Response of weeds in year 2 to herbicide treatments in year 2: June biomass assessment. (NS = no significant effect of treatments: stars = significance * p<0.05, ** p<0.01, *** p<0.001, vertical bars = 1 x SED)

Very low levels of volunteer oilseed rape were recorded in the biomass samples in year 3 and even lower levels in the spring counts in year 4. There were indications in year 3 that there were more plants on the former glufosinate plots, which concurs with the seedbank data.

Conclusion

The weed flora in this experiment was dominated by *P. annua* and this tends to influence the effects of treatments on overall weed numbers. In year 2 it appeared that the imidazolinone herbicide treatment was the least effective treatment and the glyphosate and glufosinate treatments were the most effective, but these still left appreciable quantities of weed uncontrolled. A weakness of glufosinate on *V. arvensis* and of the metazachlor and benazolin + clopyralid on this weed and on *H. vulgare* and *M. arvensis* was also noted.

Some carry over of the effects of the treatments in the rape year was recorded in the subsequent barley crops, especially in year 4, when the seeds ploughed down after the rape crop would have been returned to the surface by the second ploughing after the year 3 barley. This conclusion needs to be treated with caution as there was, for example, more *P. annua* present on the imazamox plots prior to treatment in year 2. However this does not apply to other weeds such as *M. arvensis,* where similar carry-over effects were seen.

5.4.3 NIAB - Rotation 4

Year 1 - Winter Wheat

This site was sown with winter wheat in autumn 1998. No data were collected.

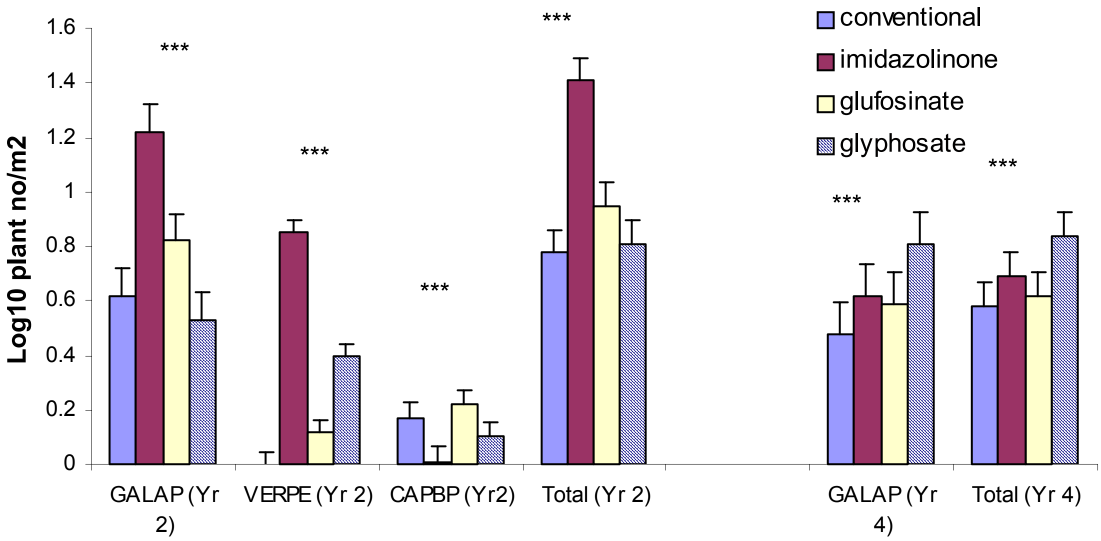


Fig 5.4.3.1. NIAB Rotation 4 : Response of weeds in years 2 & 4 to herbicide treatments applied in year 2: spring assessment of weed density (NS = no significant effect of treatments: stars = significance * p<0.05, ** p<0.01, *** p<0.001, vertical bars = 1 x SED)

Year 2 Oilseed rape

Weed levels in autumn 99 (year 2) were not particularly high (mean = 14 weeds/m^2). The flora was dominated by *G. aparine* but some volunteer wheat; *Veronica* species and *C. bursa-pastoris* were also present. In the spring, significant differences were apparent between the treatments for most of these weeds, although densities were still not high (mean = 12 weeds/m^2). The imidazolinone treatment was clearly the poorest on *G. aparine, V. persica* and the total weeds (Fig 5.4.3.1). The conventional (metazachlor and fluazifop-butyl) was particularly effective on *Veronica*.

The weed biomass in the following June was low and the only surviving weed of importance was *G. aparine* (Fig 5.4.3.2). The poor control from the imidazolinone treatment was still apparent.

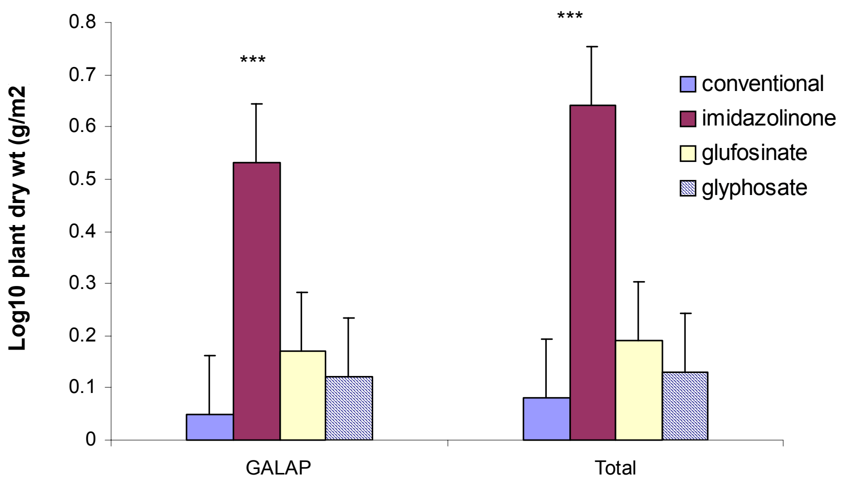


Figure 5.4.3.2 Rotation 4 at NIAB : Response of weeds in year 2 to herbicide treatments applied in year 2: biomass assessment in June (NS = no significant effect of treatments: stars = significance * p<0.05, ** p<0.01, *** p<0.001, vertical bars = 1 x SED)

Years 3 and 4 - Winter wheat

In year 3 there were virtually no weeds present in the spring (<1 plant/m^2), or in the biomass sample in June. No treatment effects from year 2 were detectable. Weed levels were still low in the final year (4 plants/m^2) and virtually the only weed was *G. aparine.* There was slightly more of this weed on the plots previously treated with glyphosate (Fig 5.4.3.1). This does not concur with the data from year 2, as the glyphosate treatment resulted in fewest *G. aparine.* This response could be linked to the fact that there were more plants of this species on these plots prior to treatment in autumn year 2 and they were ploughed up again in year 4. No weeds were present in the biomass sample.

Volunteer oilseed rape was present at very low levels in the wheat crops in the spring (<1 plant/m^2) but was absent from the biomass samples, as a result of the use of mecoprop in April to control the *G. aparine*. As the seedbank was quite low on this experiment, high numbers of volunteer plants would not have been expected.

Conclusion

In the oilseed rape the poor control of the major weed *G. aparine* by the imidazolinone treatment was clear. The other treatments were similar in effect. The weed control in the subsequent wheat, based on isoproturon, pendimethalin and mecoprop, reduced weeds to very low levels and so any impact of the year 2 treatments could not be seen.

5.4.4 Effects of treatments on species number (all sites)

The assessments of species number present in the spring, as an indicator of effects on plant diversity, show a significant effect of the four treatments in year 2 but much less effect in subsequent years. In all cases use of the covariate of number of plants counted, had a statistically significant effect. This indicated that there were appreciable differences in plant number/plot on the different treatments. As can be seen in Table 5.4.4.1, the treatment with the fewest or highest number of weed species varied across the three sites. For example, least species were found on the conventional treatment at Rothamsted but most at SAC. The herbicide treatments used in the two GM rapes tended to be intermediate in their effects. Species number/plot in general were low, particularly at NIAB.

The high level of weed control achieved in the subsequent cereal crops at Rothamsted and NIAB meant that there were few species present and therefore any continuing effect from year 2 was not apparent. Weed control was less high at SAC in year 3 but there was no significant differences due to the treatments in the previous year, but in year 4 significant differences were detected with the imidazolinone and glyphosate treated plots (in year 2) having fewer weed species than the other two. These two treatments also had fewer species in year 2. As this rotation included only one GM crop year (year 2) there is no possibility of exploring the impact of a sequence of different weed control systems.

Table 5.4.4.1 Effect of the four treatments on the number of species present at the three sites in the spring of year 2.

Site	Conventional	Imidazolinone	Glufosinate	Glyphosate	s.e.d.
NIAB	4.43	2.15	5.06	5.53	0.395
Rothamsted	3.12	10.2	8.54	7.64	0.772
SAC	6.23	3.94	5.25	4.50	0.535

5.4.5 General observations and conclusions from Rotation 4

At the three oilseed rape sites, treatment with glyphosate and glufosinate resulted in fewest weeds at SAC but the conventional at Rothamsted achieved the highest weed control. No clear pattern was apparent at NIAB except that, as at all three sites, most weeds were found on the imidazolinone treated plots. All treatments in the rape allowed the survival of some weeds. However, in the subsequent cereal crops, weed levels, especially at Rothamsted and NIAB were low, as a result of the high level of performance of the herbicides used in the wheat. At SAC more weeds survived (mainly *P. annua*) and some treatment differences were detected, indicating a possible carry-over effect from the previous rape. Analyses of weed species number tended to confirm the above conclusions, as Rothamsted had fewest species on the conventional and SAC the most. A carry-over effect of the treatments on species number was only recorded at SAC.

5.5. Rotation 5 (cereals – cereals – sugar beet - cereals)

5.5.1 Broom's Barn - Rotation 5

The main difference between Rotation 5 and the other Rotations was the inclusion of weed beet. The plots at Broom's Barn were placed on an area which had an existing weed beet problem. However, sieving of the soil seedbank samples failed to find any weed beet seed. To ensure that weed beet were present additional annual beet seed was obtained and sown into the area in 2000. In the sugar beet crop, weed beet numbers were assessed (15 August) before harvest and all mature bolted beet plants removed from the plots by hand and counted. The data of plant numbers were analysed on an area basis. Data were log transformed prior to analysis using $\log_{10}(x+1)$ due to the high number of zeros. Conventional plots had significantly more weed beet (1.3 /m^2) than either glufosinate (0.007 /m^2) and glyphosate (0.005 /m^2) plots which had practically none.

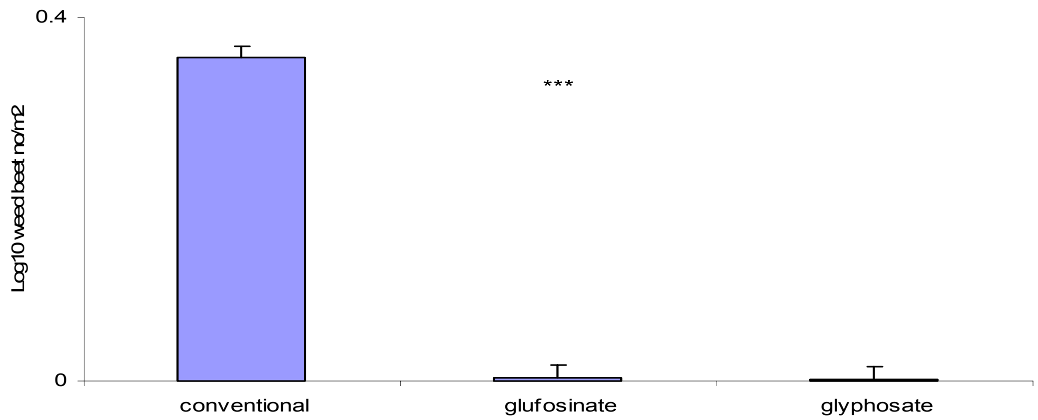


Figure 5.5.1 Numbers of weed beet removed by hand before harvest in year 3 Rotation 5, Broom's Barn. (significance *** $p<0.001$, vertical bars = 1 x SED)

These results demonstrate the value of the two herbicide tolerance systems for controlling weed beet in the sugar beet crop which is currently not feasible in conventional beet crops with selective herbicides. Weed beet can cause a yield loss of 11% for each weed beet plant/m^2 (Longden, 1993) and in this experiment prevented a potential loss of approximately 14%.

5.5.1. Morley - Rotation 5

Plate 5.5.1: Morley Rotation 5: Weed beet in conventional sugar beet plots (top) and controlled by glyphosate in glyphosate tolerant plots (bottom).

Rotation 5 at Morley followed the same protocol as at Brooms Barn, with weed beet being sown into the area in 2000. Weed beet numbers were assessed in the sugar beet crop before harvest (2nd August) and all plants were removed from plots and counted. Data were transformed prior to analysis using log10 due to the high number of zeros. Conventional plots, based on a pre-emergence treatment of chloridazon (followed by two post-emergence herbicide treatments) contained significantly more weed beet compared to the GM herbicide treatments. No weed beet was recorded in either the glufosinate or glyphosate treatments (see Plate 5.5.1.), but 0.9 plants /m2 were recorded in the conventionally treated plots. The herbicide tolerant treatments both received two applications of either glufosinate or glyphosate (2l/ha).

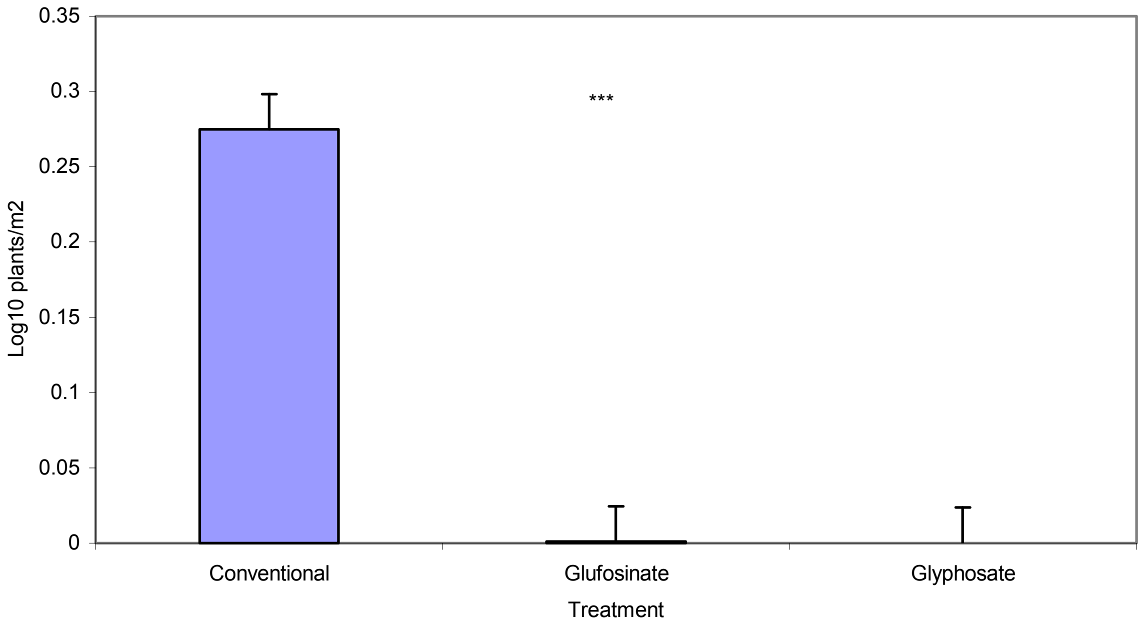


Figure 5.5.2 Numbers of weed beet removed by hand before harvest in year 3 Rotation 5, Morley. (stars = significance, *** p<0.001, vertical bars = 1 x SED).

Conclusions

These results show that the HT treatments are both very effective for weed and volunteer beet control while generally being "safe" on HT beet. They provide a good spectrum of weed control and enhance flexibility of timing of application. They provide an effective system for the control of weed beet in sugar beet, though this value would be jeopardised if the HT beet crops were allowed to flower and thus cross-pollinate with the weed beet, producing HT weed beet.

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Chapter 6 (Pages 147-183)

6. Oilseed Rape Yields and Volunteers

Whenever the rotations required the planting of oilseed rape, plots were harvested at the different sites using the methods (swathing, desiccation or direct combine harvesting) shown in Tables 4.3.4 – 4.3.6, with an appropriate plot combine, and yields were determined. At least one strip, and in some cases two or three strips, were harvested from each plot, so that a robust estimate of plot yields could be obtained. The primary aim of the work was not to assess the relative yields of the different treatments, as the herbicide tolerant cultivars were not the fully commercial varieties that would be sold to farmers, once the technology reached full commercialisation. But information on yields was needed in relation to the level of post-harvest seed losses and for overall consideration of the realism of the crops grown on the experiments, in relation to crop establishment, weed competition etc. The aim of the work was to endeavour to reflect commercial production systems, within the constraints of a field experiment, so there was a need to record how realistic the crops were and seed yield is a good basis on which to evaluate this.

As the rape crop reaches maturity the pods become brittle and tend to split open shedding their seeds. This shedding can be triggered by wind and heavy rain, but is primarily caused by harvesting operations. Work by a number of workers in the 1980s and 1990s has quantified this loss and showed that it tends to increase with delay in harvesting (Price *et al*., 1996; Gulden *et al*., 2003). Some growers, in an attempt to minimise this problem swathe the crop prior to maturity, allowing it to mature in the swathe and then picking up and threshing the swathed crop at harvest time. Weather conditions will largely determine whether or not this results in less shedding, but swathed crops are less vulnerable to wind and so swathing is commoner in the upland and northern counties than in the south. When the rape crop is harvested seeds fall off the rape plants as the crop shakes in advance of the arrival of the harvester and at the cutter bar, and may also be returned to the field with the straw at the back of the machine. The extent of losses determines the initial levels of seed return to the soil and the potential volunteer rape populations.

6.1 Oilseed rape Yields and Harvest seed losses

6.1.1 Yields

Three rotations included oilseed rape (Rotations 1, 3 and 4). At Rothamsted and SAC Rotation 1 was split into two similar sub units for some assessments and so yields were recorded for each sub unit (Rotation 1a and 1b). The imidazolinone resistant cultivar was no longer available in year 4 and so was omitted from the results.

NIAB

Yields varied from less than 2.5 t/ha to more than 4 t/ha (Fig 6.1.1.1). Highest yields tended to be produced by the conventional cultivar (Apex) and by the glyphosate tolerant one. Lowest yields were produced by the imidazolinone tolerant cultivar. However, statistically significant differences were only recorded in Rotation 1 in year 1.

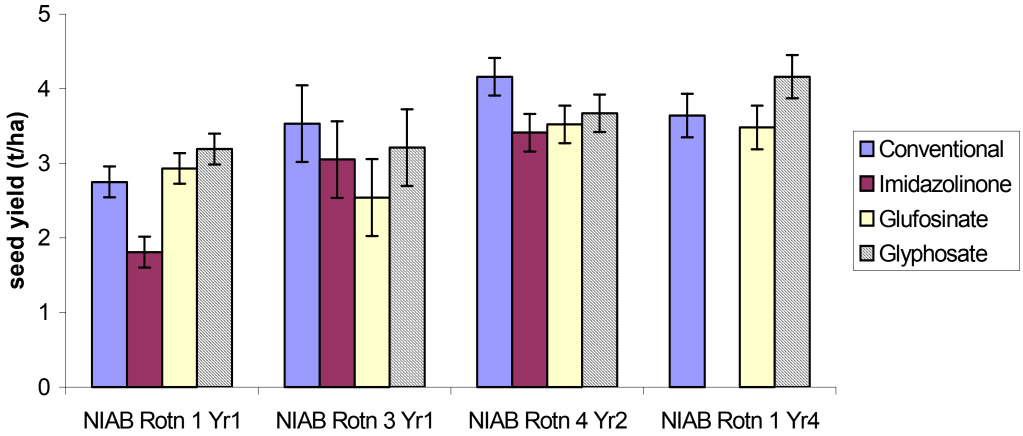

Figure 6.1.1.1 NIAB, yields of the oilseed rape cultivars in year 1 (rotation 1 and 3), year 2 (rotation 4) and year 4 (rotation 1) Vertical bars = 2 X SED

In Rotation 1 year 1 one of the Imidazolinone tolerant plots (plot 4) was flooded during the winter resulting in stunted growth which probably reduced the yields and reduced the canopy size of the plants. In addition 'conventional' plot 1 was severely grazed by pigeons reducing the size and hence yields of the plants. In Rotation 1 in year 4 there was a high infestation and subsequent contamination of harvested seed with *A. myosuroides* seed in many of the plots which may have affected yields.

Rothamsted

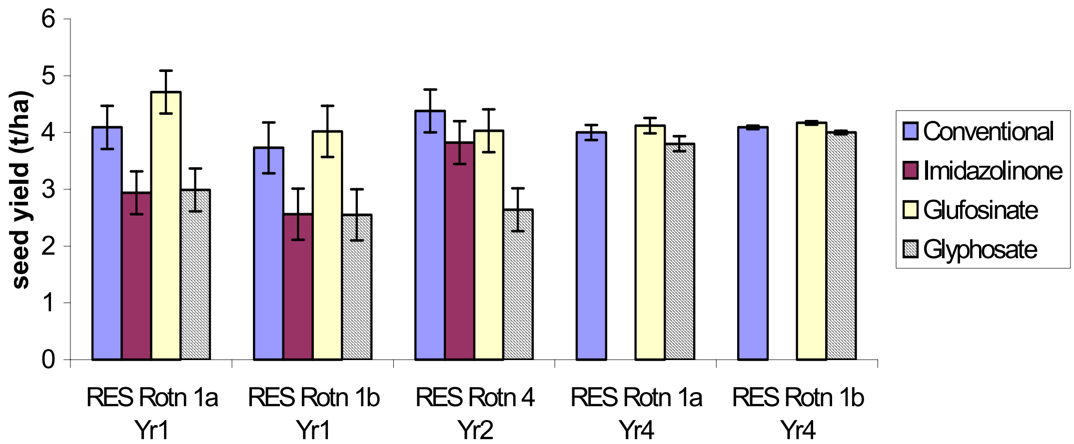

Figure 6.1.1.2 Rothamsted yields of the oilseed rape cultivars in year 1 (rotation 1), year 2 (rotation 4) and year 4 (rotation 1) Vertical bars = 2 X SED

Varietal response varied between the years. Highest yields in year 1 were recorded on the conventional rape plots (Apex) and on those sown with the glufosinate tolerant rape. In Rotation 4 year 2 the glyphosate tolerant rape plots yielded least. This was because of a high level of pigeon grazing just prior to harvest. In year 4 the three cultivars yielded similarly (Fig 6.1.1.2)

Plate 6.1.1. Harvesting oilseed rape in rotation 1, year 1 at Rothamsted.

Scottish Agricultural College

Rape yields were lower at the Scottish site, especially in year 2 where the isolated patches of smaller plots in Rotation 4 were more vulnerable to pigeon attack over winter (Fig. 6.1.1.3). Year 4 crops were earlier drilled and established better. The glufosinate tolerant cultivar tended to give the highest yields and the imidazolinone tolerant cultivar the lowest.

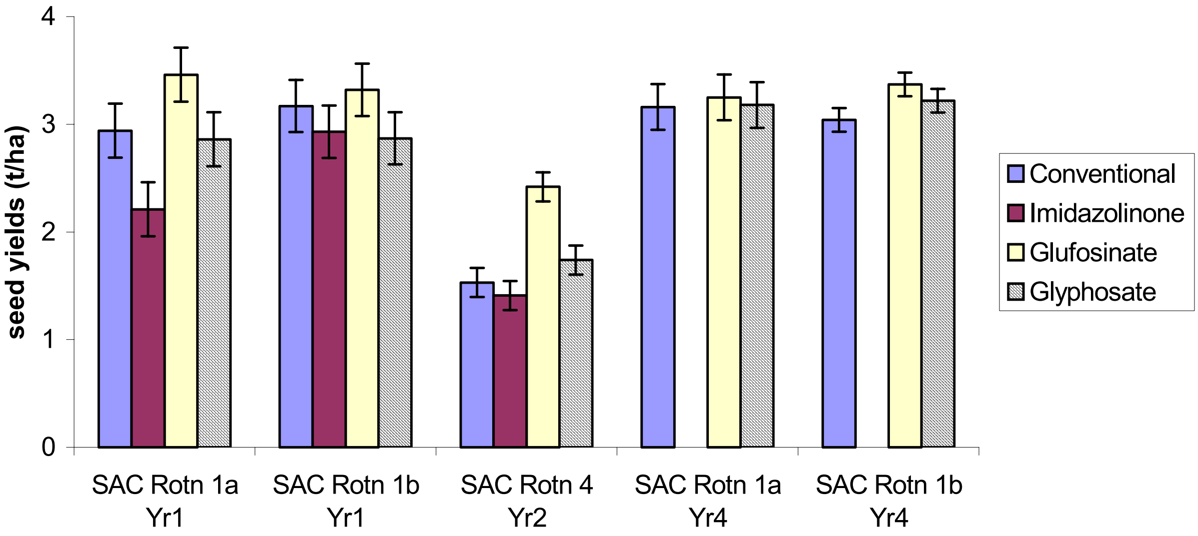

Figure 6.1.1.3 Scottish Agricultural College, yields of the oilseed rape cultivars in year 1 (rotation 1), year 2 (rotation 4) and year 4 (rotation 1) Vertical bars = 2 X SED

Morley and Brooms Barn

These two sites only grew oilseed rape in the first year, as Rotation 3 required the sowing of sugar beet later in the rotation. At Morley the imidazolinone tolerant cultivar had significantly lower yields. At Brooms Barn yields were low and there were no major differences between treatments (Fig. 6.1.1.4)

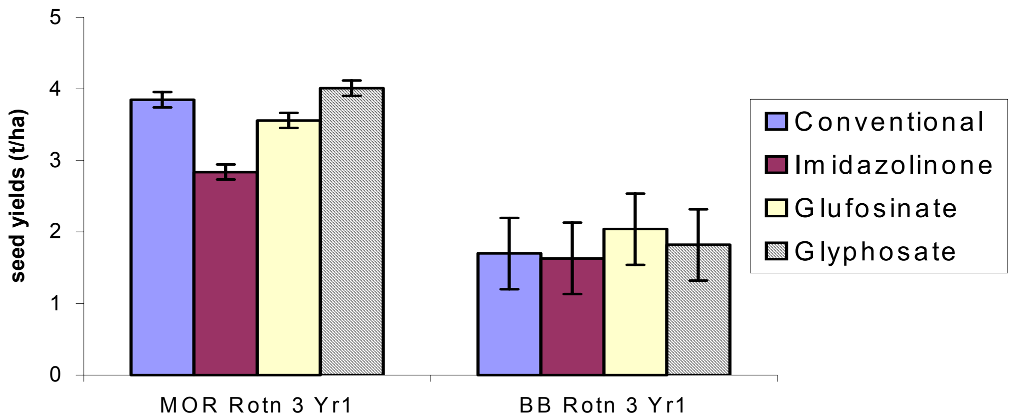

Figure 6.1.1.4. Morley (MOR) and Brooms Barn (BB). Yields of the oilseed rape cultivars in year 1 (rotation 3). Vertical bars = 2 X SED

Yields across all sites

When the yields from all sites are amalgamated overall yields were in the region of 3t/ha with an indication of slightly lower yields from the imidazolinone tolerant cultivar. However, it must be noted that this comparison is not fully orthogonal, as the imidazolinone tolerant rape was not grown in year 4. Differences between the other three cultivars were small (Fig. 6.1.1.5). The mean yield of 3.16 t/ha equates well with the national average yields for the years 1999 – 2002 of 3.00 t/ha (statistics.defra.gov.uk), indicating that the crops grown on these experiments reflected 'normal' cropping.

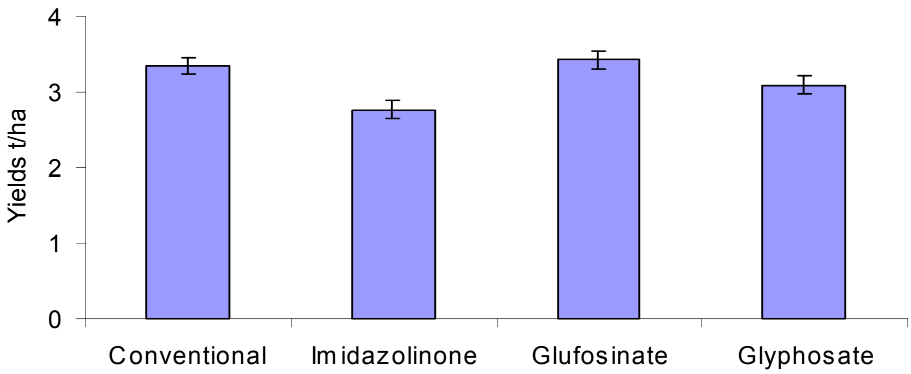

Figure 6.1.1.5. Yields of the oilseed rape cultivars: mean yields across all sites.

Plate 6.1.2 . NIAB Rotation 1 year 1. Unloading a plot of oilseed rape into a trailer prior to weighing.

Plate 6.1.3 . NIAB Rotation 1, year 1. Bagging a plot of oilseed rape from a trailer prior to weighing.

6.1.2 Seed losses at harvest

Seed losses were measured at harvest at most of the BRIGHT sites, either by counting seeds in quadrats immediately after harvest or from seeds collected in gutters placed in the crop at harvest. Both methods have advantages and disadvantages but give reasonably sound estimates of losses. Overall losses were in the region of 4000 seeds/m^2, (grand mean 3575 seeds/m^2 (s.e. 400)) which is high in relation to the 100 seeds/m^2 sown initially to establish the crop. However, seed losses reached 10,000 seeds/m^2 at some sites, on some treatments, in some years (e.g. Broom's Barn Rotn 3, Yr1; Rothamsted Rotn 4, Yr 2) (Fig 6.1.2.1). These high losses tended to be associated with increased pigeon attack prior to harvest and were not thought to be linked to any intrinsic characteristic for shattering in the cultivars concerned, as there were no overall significant differences in losses between the four types of rape. All cultivars were harvested on the same day at each site, apart from SAC where swathing and harvesting were conducted by plot maturity. It was also clear that there was no obvious link between the overall yield and the level of shedding, as other factors overrode any link between seed number (as reflected in yields) and seed loss (Fig. 6.1.2.2).

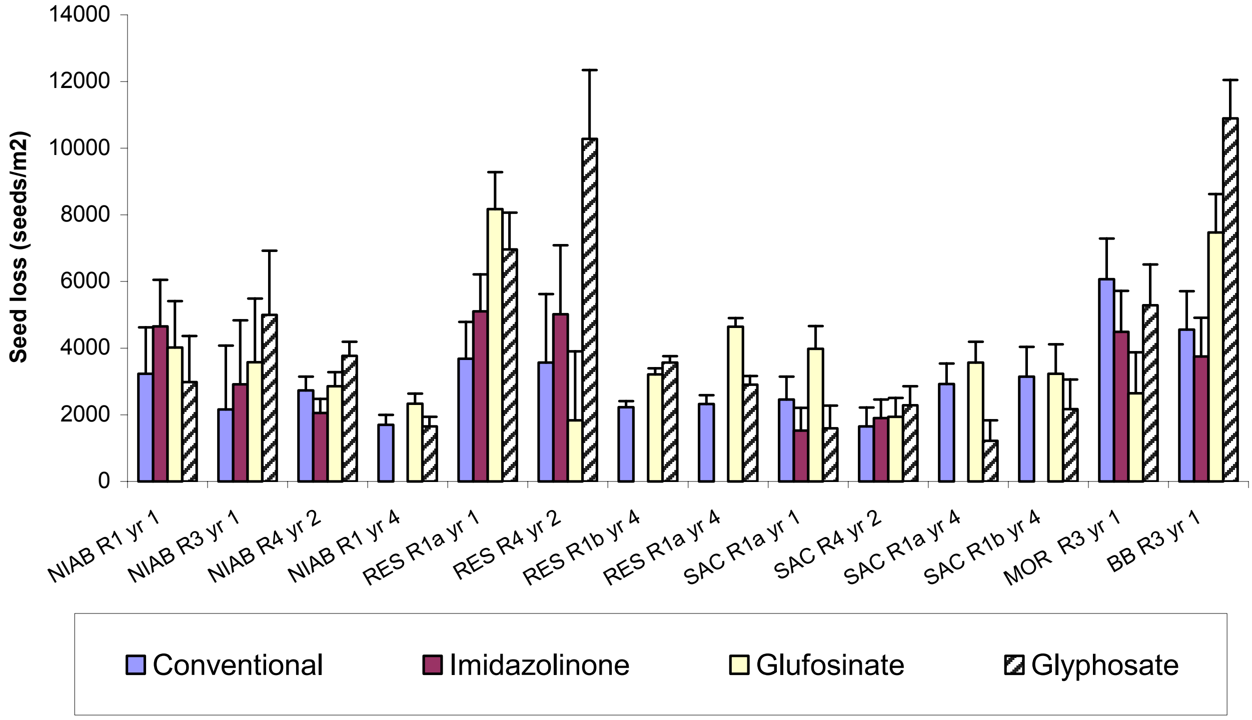

Figure 6.1.2.1 Overall effect of oilseed rape cultivar on seed losses at harvest at fourteen studies (5 sites, 3 years) (vertical bars = 1 x SED)

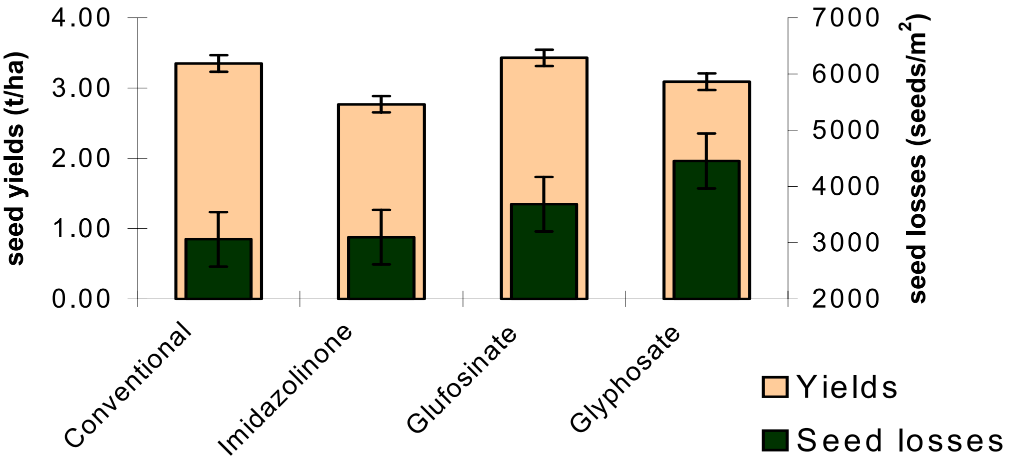

Figure 6.1.2.2. Comparison of mean seed yields for the four rape cultivars and mean seed losses at harvest (vertical bars = +/- 1 x SED)

The seeds lost at harvest are the primary source of subsequent infestations of volunteer rape. At some sites post harvest counts of seeds were linked to subsequent counts of seedlings. These were linked to rainfall events.

6.2 Post-harvest seed counts and seed germination

Rothamsted 1999 (Rotation 1a)

At harvest in July 1999, seed losses were between 4000 and 8000 seeds m^{-2} (Fig. 6.2.1, Plate 6.1.3 and see also the previous section). Most seeds were on the glufosinate and glyphosate plots. These seeds remained ungerminated on the soil surface for the first 10 days, as there was virtually no rainfall (Fig.6.2.2). Over 10mm of rain fell on day 14 and after some modest further rain a substantial storm resulted in a further 35mm on day 18. As a result of all the precipitation, by day 22, most (if not all) of the seeds had germinated. No surviving seeds were identified in the quadrats. There is also some indication of an increase in seedling numbers, compared to the seed assessment done on Day 10 (Fig. 6.2.1). As seeds were excavated from soil cores later in the winter (see below) some seeds clearly did not germinate prior to cultivation and burial, but the proportion of the shed seeds that survived was clearly relatively low.

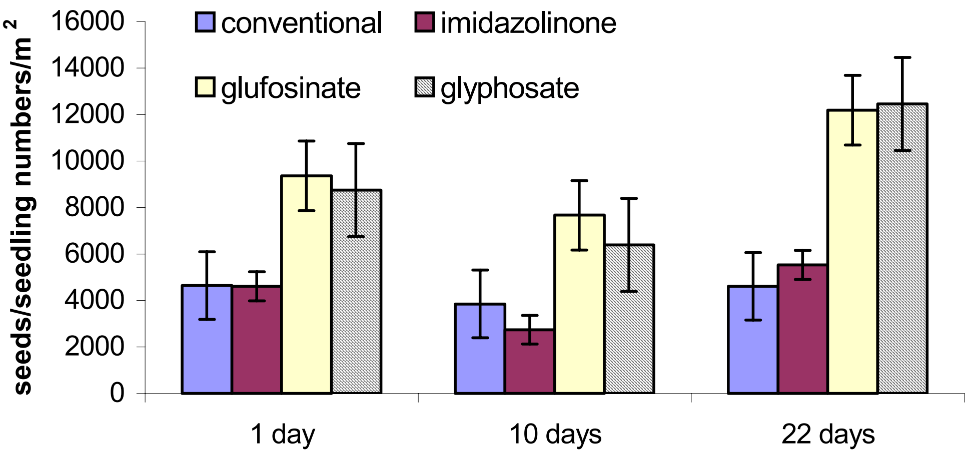

Figure 6.2.1 Rothamsted, Rotation 1: effect of rape cultivar on the number of seeds present 1 and 10 days after harvest and the number of seedlings present after 22 days in 1999 (vertical bars = 2 x SED)

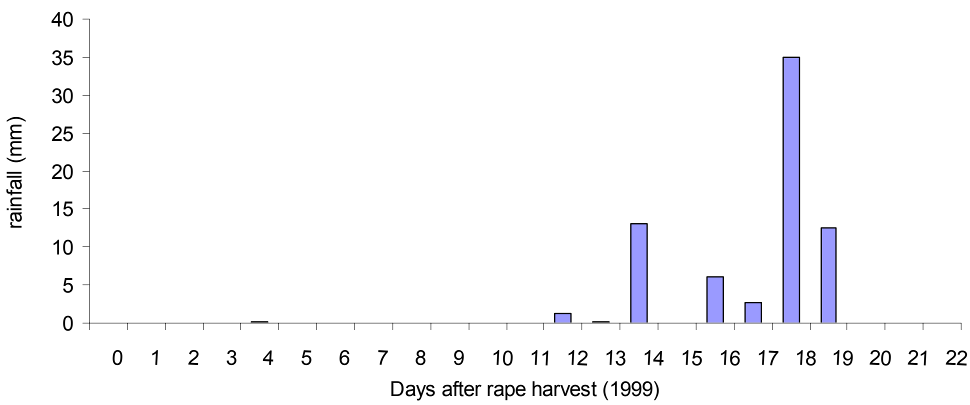

Figure 6.2.2 Rothamsted: rainfall in 1999 for the 22 days after the harvest of the rape crop on 21 July

Rothamsted 2000 (Rotation 4)

Seed losses at harvest of the rape plots of Rotation 4 reached 10,000 seeds m^{-2} for the glyphosate resistant cultivar. Losses were significantly lower for the other three cultivars (Fig. 6.2.3).

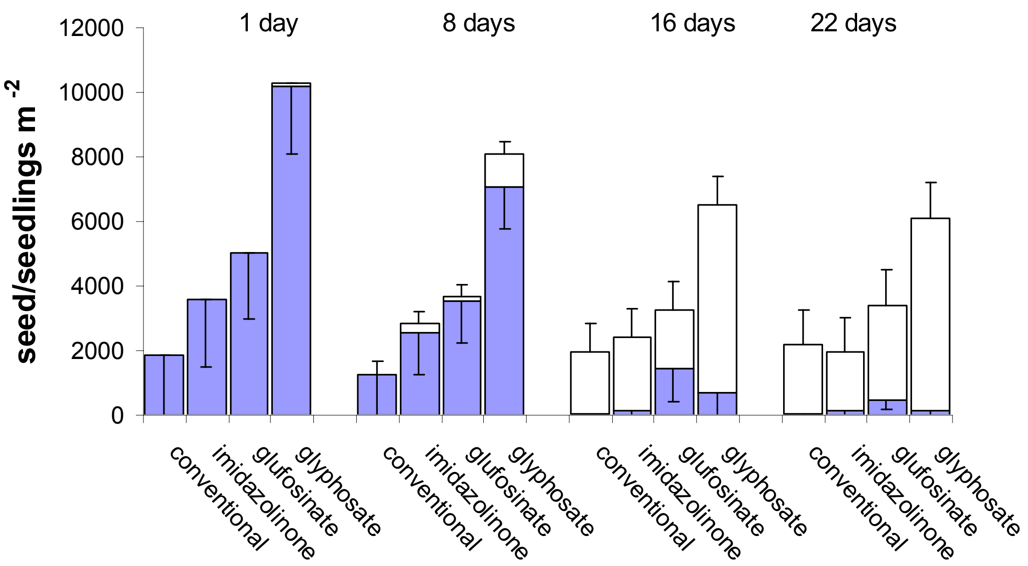

Figure 6.2.3 Rothamsted, Rotation 4: effect of rape cultivar and time on the number of rape seeds post-harvest and on their subsequent germination after 8, 16 and 22 days in 2000 (vertical bars = 1 x SED) seeds = dark columns: seedlings = white columns.

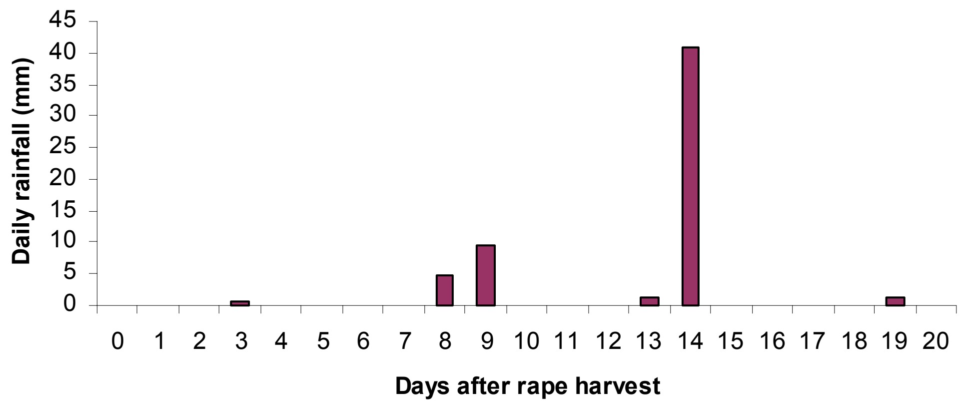

Figure 6.2.4 Rothamsted: rainfall in 2000 for the 20 days immediately after the harvest of the rape crop on 25 July.

Plate 6.2.1 Rothamsted Rotation 1. Oilseed rape volunteers from seed incorporated in year 1 controlled by glufosinate in glufosinate tolerant rape seedlings in year 4. Also note effect on volunteer wheat.

Plate 6.2.2. Rothamsted Rotation 4. Oilseed rape volunteers from seed shed at or before harvest coming up in rape stubble in autumn of year 2.

After 8 days, most seeds remained on the plots, though a small minority had germinated, despite the lack of appreciable rainfall post-harvest. There was 14mm of rain on days 8 and 9 (Fig. 6.2.4) and this seems to have been sufficient to cause the majority of seeds to germinate. The further 40mm on day 14 ensured that most seeds germinated by day 22. Interestingly there was a still a small minority of ungerminated seeds (c. 200seeds/m^2) at day 22. There is also evidence of a decline in seed/seedling numbers over time, suggesting that there was a modest level of seed predation.

Scottish Agricultural College 2000 (Rotation 4)

Seed numbers varied from 1000 to 4000 seeds/m^2, under the swathe of the rape crop, immediately after harvest (Fig 6.2.5). The cultivars were harvested on different dates with the glyphosate resistant cultivar being harvested nearly two weeks later than the other three, owing to its later maturity.

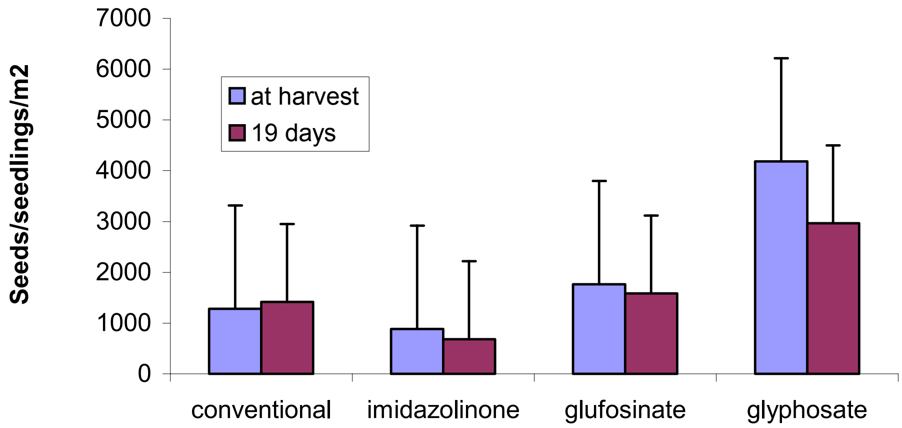

Figure 6.2.5 Scottish Agricultural College, Rotation 4: the numbers of shed seeds by the rape cultivars at harvest and seedlings present 19 days later (quadrats assessed in areas under the combine swathe) in 2000 (vertical bars = 1 x SED)

No statistically significant differences were detected between the cultivars, as the data were rather variable but there were indications of more seeds left on the plots of the late harvested glyphosate cultivar. Two and a half weeks after harvest no seeds were found and similar numbers of seedlings were present. This was due to the frequent appreciable periods of rain (in excess of 10mm) after all the harvest dates (Table 6.2.6).

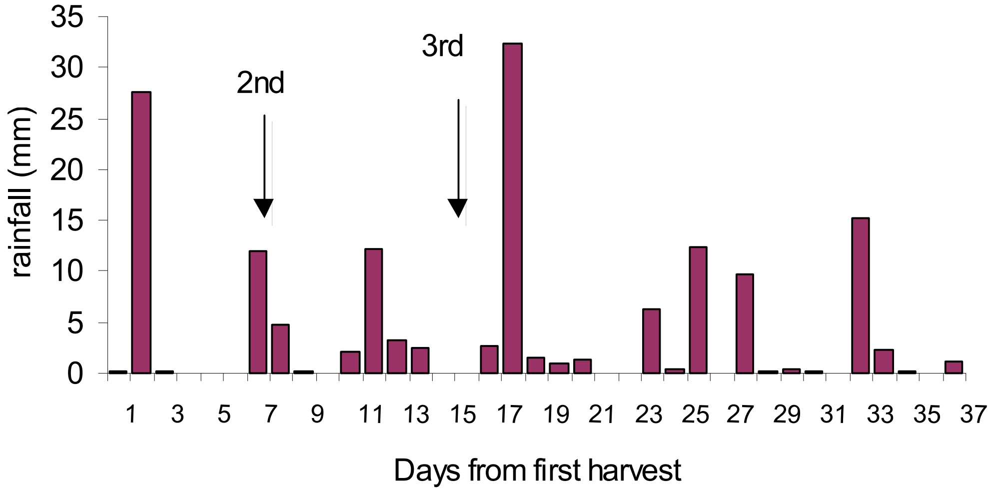

Figure 6.2.6 Scottish Agricultural College: rainfall in 2000 for the 37 days following the first harvest of the rape crop on 25 August (glufosinate rape harvested 25 Aug; conventional and imidazolinone 30 Aug (2nd); glyphosate 11-18 Sept (3rd))

Rothamsted 2002 (Rotation 1)

Immediately after harvest on 24 July seed numbers were estimated to be between 2000 and 4000 seeds/m^2 (Fig. 6.2.7). Significantly fewer seeds were found on the plots that had grown the conventional rape cultivar.

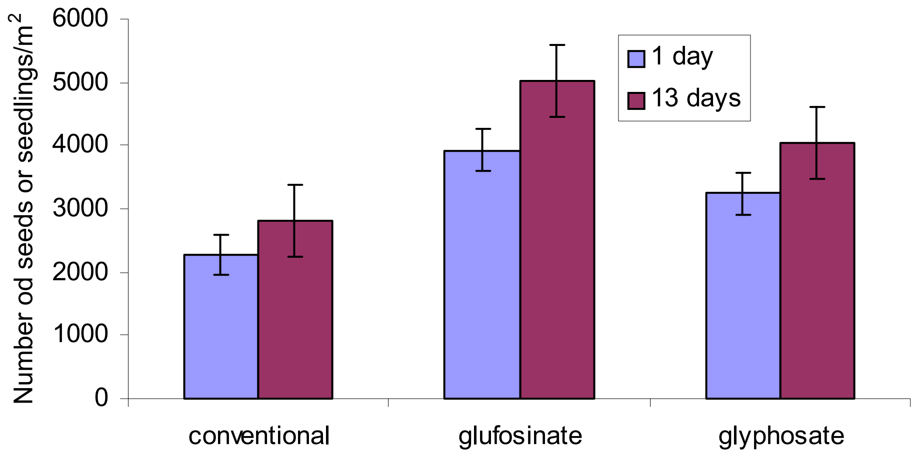

Figure 6.2.7 Rothamsted, Rotation 1: the number of seeds/m^2 present one day post-harvest of the rape cultivars and the number of seedlings/m2 after 13 days in 2002. (vertical bars = 2 x SED)

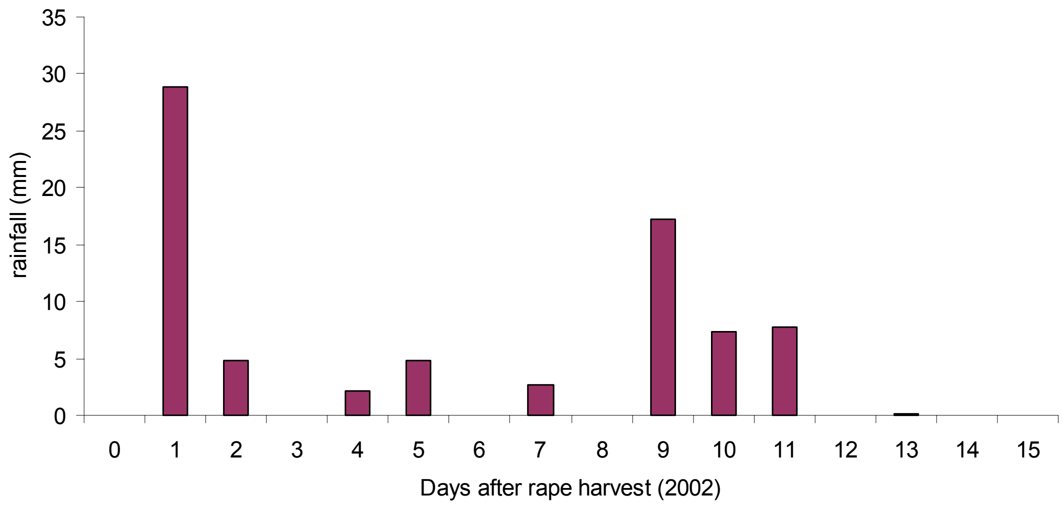

Figure 6.2.8 Rothamsted: rainfall for the first fifteen days after the harvest of the rape crop on 24 July, 2002.

As in the other examples, approximately 2 weeks later few seeds remained and equivalent numbers of seedlings were counted. Seedling germination was stimulated by the substantial rain (c. 30mm) on the day after harvest (Fig. 6.2.8).

Conclusions from information on seed losses

These estimates of seed and seedling numbers clearly demonstrate that if seeds are left on the soil surface and there is 'significant rainfall' most will germinate and thus will not be introduced into the seedbank. However because the numbers shed onto the soil can be very high (up to 10,000 seeds/m^2) only a few percent survival will still result in a detectable seedbank in later years. Allowing the shed seeds to germinate will clearly assist in the substantial depletion of the potential seedbank, and so should be promoted as a prime method of control. In these examples rainfall exceeded 10mm on all sites and this was clearly adequate to encourage extensive germination.

6.3 Decline in the oilseed rape seedbank over the four years of the BRIGHT project.

From the earlier section of this part of the report, it is clear that substantial numbers of volunteer rape seeds were shed at harvest. Some of these seeds became incorporated into the soil seedbank by the post-harvest cultivations. These seeds formed the basis of a persistent seedbank. Plots were sampled in the first winter, after the rape harvest and then every winter thereafter. For the sites growing rape in Rotations 1 and 3, this provided up to four data sets and for those growing Rotation 4 (where the rape was sown in year 2) it provided three sets of data. There were eleven site/rotation comparisons (Table 6.3.1).

Table 6.3.1 Details of the sites and rotations where assessments of volunteer rape seeds were done

Site	Rotation	Assessment of harvest seed shedding	Soil core assessment after c. 6 months	Soil core assessment after c. 18 months	Soil core assessment after c. 30 months
Rothamsted	1a	Y	Y	Y	Y
	1b	N	Y	Y	Y
	4	Y	Y	Y	*
NIAB	1	Y	Y	Y	Y
	3	Y	Y	Y	Y
	4	Y	Y	Y	*
SAC	1a	Y	Y	Y	Y
	1b	N	Y	Y	Y
	4	Y	Y	Y	*
Morley	3	Y	Y	Y	Y
Brooms Barn	3	Y	Y	Y	Y

Y = data available; N = data not collected. * In Rotation 4 rape was sown in Year 2 so no data available

Initially each year's data were analysed using standard analysis of variance to determine whether there were significantly more seeds of one rape cultivar than another. Overall means were also calculated in order to compare changes with time between the sites and rotations. Subsequently, regression analyses were done to predict longer-term decline rates (see below).

Effect of treatments

Analyses were done on all the data sets identified in Table 6.3.1 to ascertain whether there were major treatment effects. The analyses were not very strong, as for many data sets there were only two replications. Despite this, statistically significant differences were recorded at a number of sites.

Rothamsted

In Rotation 1a, statistically significant differences were recorded in years 3 and 4. However, although not exceeding the 5% probability level, similar trends seemed apparent in Year 1 and for the first soil samples in Year 2 (Fig. 6.3.1).

In all years most seeds were found on the glufosinate treated plots. In years 3 and 4 least seeds were present on the plots formerly growing imidazolinone tolerant rape. The decline in seed levels between Year 1 (seeds shed at harvest) and Year 2 (soil cores after c. 6 mths) was particularly marked. This arose because these plots were deliberately left uncultivated after harvest for c. 4 weeks, prior to burial, in accordance with normal/good agricultural practice.

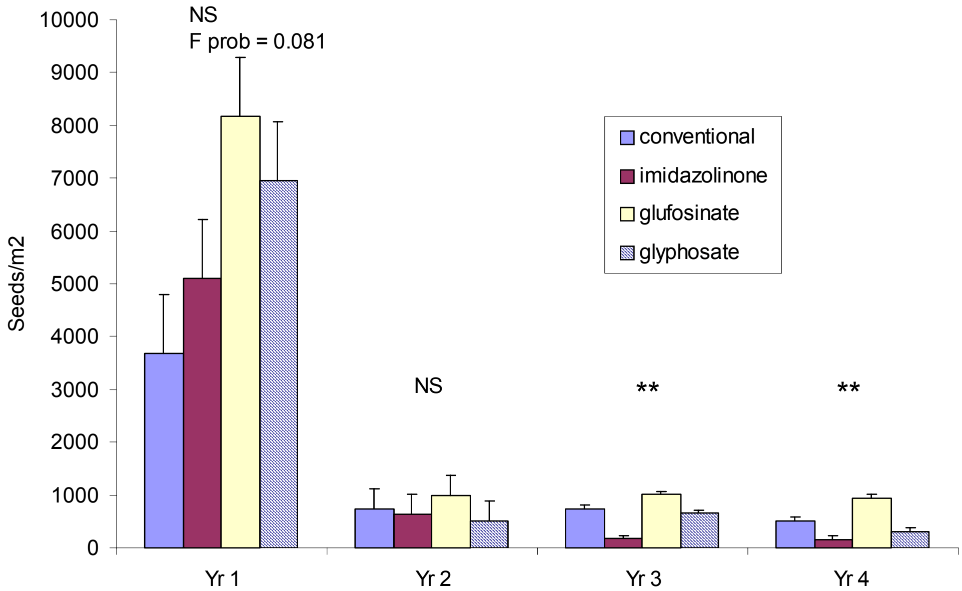

Figure 6.3.1. Rothamsted, Rotation 1: numbers of seeds shed at harvest and found in the seedbank in Years 2, 3 and 4 (6 months, 18 months and 30 months post harvest) (vertical bars = 1 x SED)

In rotation 4, where oilseed rape was grown one year later than Rotations 1a and 1b, there were again statistically significant differences between the four cultivars. In this experiment most seeds were found on the glyphosate tolerant rape plots and least on the conventional (Fig.6.3.2). This applied to all three samples.

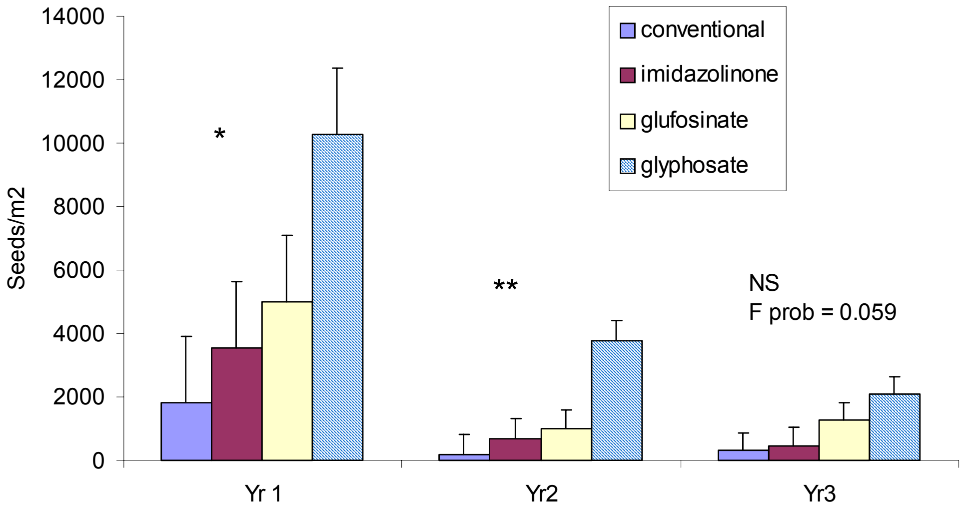

Figure 6.3.2. Rothamsted, Rotation 4: numbers of seeds shed at harvest and found in the seedbank in Years 2 and 3 (6 months, and 18 months post harvest) (vertical bars = 1 x SED)

NIAB

There were no detectable treatment effects in Rotation 3 and only in the fourth year of Rotation 1 was a significant effect detected ($p<0.05$). Most seeds in Year 4 of rotation 1 were on the glufosinate and conventional plots. No effects were detectable in earlier years. The first year of Rotation 4 indicated that more seeds had been shed by the glyphosate tolerant rape ($p<0.05$). These effects were not apparent in later years. Overall means are presented in Table 6.4.1.

SAC

No detectable treatment effects were recorded for Rotations 1b and 4 at SAC. Overall means are presented in Figure 6.4.1. In the first and third years of Rotation 1a most rape was present on the plots that had previously contained glufosinate tolerant rape (Fig 6.3.3). It should be noted that there was some survival of volunteer rape in the cereal crop in Year 3 of Rotation 1 and so the number of seeds extracted in the 30 month sample could have been inflated by seeds from these volunteers. This may account for the lack of decline in the seedbank in Rotations 1a and 1b in Fig. 6.4.1.

Morley and Broom's Barn

These two sites only grew rape in Rotation 3. The data were rather variable at Broom's Barn. In the first year significantly more seeds were present on the plots that had previously grown the glyphosate tolerant cultivar ($p<0.05$). This effect was not apparent in later years. No statistically valid comparisons between treatments were found at the later assessments. No treatment effects were noted for the Morley site. Overall means are presented in Table 6.4.1.

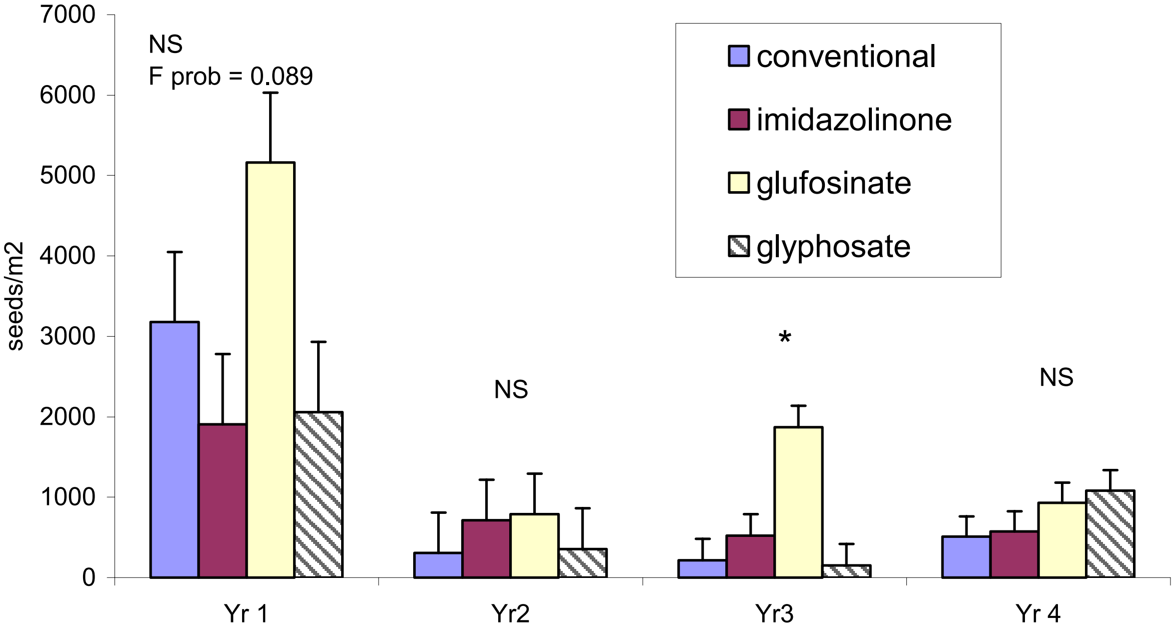

Figure 6.3.3 Scottish Agricultural College, Rotation 1a: numbers of seeds shed at harvest and found in the seedbank in Years 2, 3 and 4 (6 months, 18 months and 30 months post harvest) (vertical bars = 1 x SED)

Conclusions

Where statistically significant effects were noted, they tended to originate from the number of seeds shed at harvest. These effects sometimes continued into later samples, but not always. The results were not consistent, as sometimes most seeds came from the glufosinate tolerant rape plots and sometimes from the glyphosate plots. Statistically significant comparisons were found on only 9 of the 49 site/rotations/years. The experiments did not detect major differences in persistence between the four rape cultivars, and the herbicide tolerant ones (glyphosate, glufosinate) were no more persistent than the conventional cultivar (Apex). Where differences were identified these seem to be associated with increased seed shedding at harvest, rather than differences in subsequent persistence. More detailed studies of the decline rates are presented in Sections 6.4 and 6.5.

6.4 Overall estimates of decline in the oilseed rape seedbank at eleven sites

Overall means and standard errors were calculated for all sites. Seed loss at harvest was about 4000 seeds/m^2. This has been discussed in more detail in Section 6.2 on seed loss at harvest. There was then on average a 60% decline in seed numbers over the first 6 months, followed by a much lower decline of 5-10% in the subsequent two years. The initial decline was influenced by post-harvest cultivations. Decline rates between 6, 18 and 30 months varied considerably between sites and rotations. For example losses were high at Morley (MOR) but were very low at Scottish Agricultural College (SAC) (Fig. 6.4.1). This seemed to indicate that decline rates were lower in the cooler Aberdeen than in the warmer and lighter soil Norfolk (MOR). More specific experiments would be needed to confirm this.

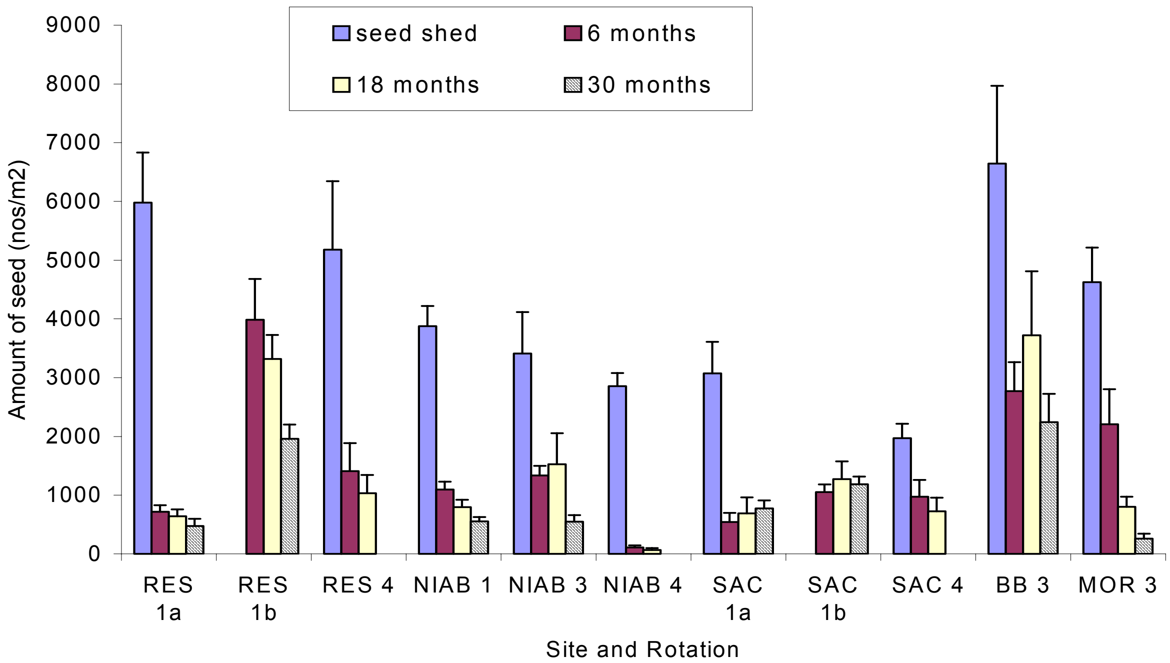

Figure 6.4.1 Overall decline rates for oilseed rape after c. 6, 18 and 30 months following seed shed at harvest at 11 sites. (RES, NIAB, SAC, BB, Mor = sites; Numbers refer to rotations 1, 3 or 4) Vertical bars = 1x standard error of mean)

Appreciably more seeds were present at 6, 18 and 30 months on the Rothamsted and SAC rotation 1b, than on rotation 1a. This was because rotation 1b was ploughed immediately after harvest, whereas rotation 1a was left for approximately 4 weeks. The 'immediate' ploughing on rotation 1b, prevented assessments being made on seed shedding at harvest, but as the two rotations were adjoining there is no reason to think that seed losses in rotations 1a and 1b would have been different. This comparison confirms the benefit of leaving rape stubbles uncultivated, as many fewer seeds become incorporated into the seedbank. This aspect of the behaviour of rape seeds has been discussed in the previous section. This conclusion that delayed cultivation reduces the seedbank, confirms earlier work described by Pekrun *et al* (1998).

Variations in the rates of seed decline between sites are clearly apparent in Fig. 6.4.1. Decline appears rapid at Morley but at SAC after the initial decline over the first 6 months, there was little further decline. This may be due to additions to the seedbank arising from no control of volunteer rape plants in the barley crop in Year 4.

6.5 Modelling decline in the oilseed rape seedbank

Where there were four data sets for each site (seed loss in 1999 and soil seedbank samples in following three seasons) regression analyses were attempted to estimate decline rates for the seeds. The model used was an exponential decline model of $Y = A + BR^X$, where A is the asymptotic density, B is the decline from the initial numbers to the asymptote, so that A+B is the number of seeds at time zero, and R is the annual decline rate. For various reasons complete data sets were only available for the following rotations Rothamsted 1a, NIAB 1, NIAB 3, SAC 1a, Morley 3 and Brooms Barn 3. The data from SAC did not seem to follow an exponential decline (see Fig. 6.4.1) and those from Brooms Barn were very variable. Consequently neither would 'fit' the exponential model, leaving four data sets where decline curves could be fitted; Rothamsted 1a Morley 3, NIAB 1 and NIAB 3. At two sites there were significant differences between the four rape cultivars, Rothamsted 1a and NIAB 1. At the other two sites any varietal differences were not detectable (Table 6.5.1).

Table 6.5.1 Parameter values from the regression analyses calculating the decline rates of rape seeds and four sites (figures in brackets are standard errors of parameter values)

Site	Rotn	Cultivars	Parameters			% va*
			A	B	R	
Morley	3		-478 (1180)	5113 (1169)	0.515 (0.181)	65.3
NIAB	1	Apex	867 (253)	2381 (485)	0.128	85.6
		IMI	611 (272)	4021 (491)	(0.072)	
		Glufosinate	911 (261)	3126 (487)		
		Glyphosate	603 (254)	2426 (485)		
		Synergy	290 (274)	4174 (492)		
NIAB	3		465 (216)	2579 (644)	0.288 (0.259)	42.8
Rothamsted	1a	Apex	636 (337)	3050 (664)	0.025	90.8
		IMI	271 (347)	4840 (668)	(0.062)	
		Glufosinate	920 (366)	7253 (678)		
		Glyphosate	433 (360)	6525 (675)		

Cultivars tested: conventional (Apex), imidazolinone tolerant (IMI), glufosinate tolerant, glyphosate tolerant, conventional (Synergy) (NIAB only)

* %va = % variance accounted for by the model

A is the asymptotic density, B is the decline from the initial numbers to the asymptote, R is the annual decline rate

Rothamsted - Rotation 1a

The analysis accounted for more than 90% of the variation in the data (Fig 6.5.1, Table 6.5.1). At this site the highest number of seeds were present throughout the experiment on the glufosinate rape plots. This confirms the conclusion of the earlier analysis of variance on the data from each year. There was a steep decline in the first year, followed by lower losses in subsequent years. With the conventional variety Apex the asymptote was reached with 17% of the seeds still in the seedbank and for the glufosinate rape 11%.

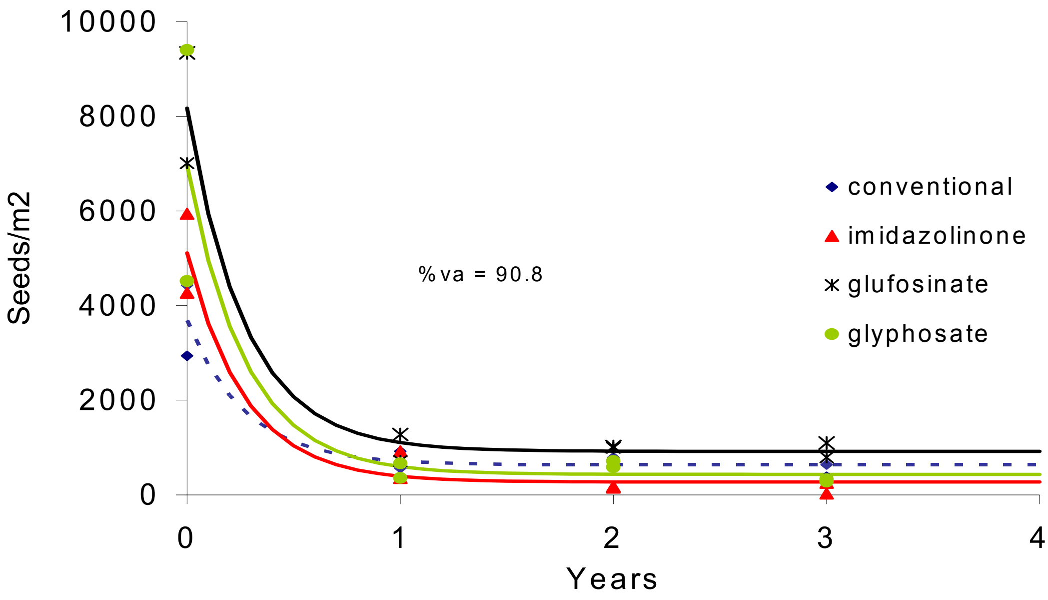

Figure 6.5.1 Rothamsted Rotation 1a: modelled declines of the seedbanks of the four rape cultivars from the initial seed shed in summer 1999 and for the following three seasons. (- - - ♦ - - conventional (Apex); ——— ▲ ——— imidazolinone; ——x—— glufosinate : ———●——— glyphosate)

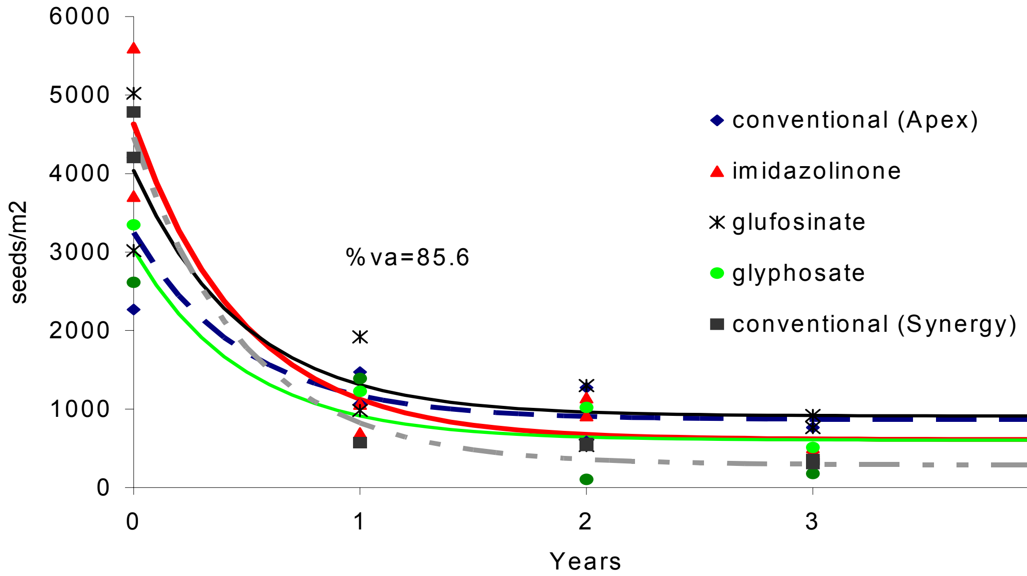

Figure 6.5.2 NIAB Rotation 1: modelled declines of the seedbanks of five rape cultivars from the initial seed shed in summer 1999 and for the following three seasons (- - - ♦ - - conventional (Apex); ——▲—— imidazolinone; ——x —— glufosinate : ——●—— glyphosate: - - - ■ - - - - conventional (Synergy))

NIAB - Rotation 1

In rotation 1 at NIAB the conventional plots were split between two cultivars, Apex and Synergy (a varietal association consisting and a male sterile hybrid and a conventional variety in the ratio of 4:1). The conventional variety Apex and the glufosinate tolerant rape were the most persistent cultivars, as was apparent from the analysis of variance in Year 4. The conventional (varietal association) Synergy was least persistent (Table 6.5.1, Fig. 6.5.2). The regression model accounted for 86% of the variance in the data. The decline in the first year was not as great as had been recorded at Rothamsted. When the asymptote was reached for Apex, over 26% of the seeds remained and 23% of glufosinate seeds were also present, but for Synergy only 6% of the seeds remained. As with the Rothamsted 1a data, appreciable numbers of seeds were predicted to persist for some years after the end of the experiment.

NIAB - Rotation 3

With this site there were no significant differences between the four cultivars, as had been shown by the previous analysis of variance. The data did not fit the model quite as well as for the other three sites but still accounted for 42% of the variance. The decline rate in the first year was slower than for the Rothamsted

Rotation 1a and the NIAB Rotation 1 sites but 24% of the seeds were predicted to be present at the end of the experiment and which would remain for subsequent years (Table 6.5.1, Fig. 6.5.3).

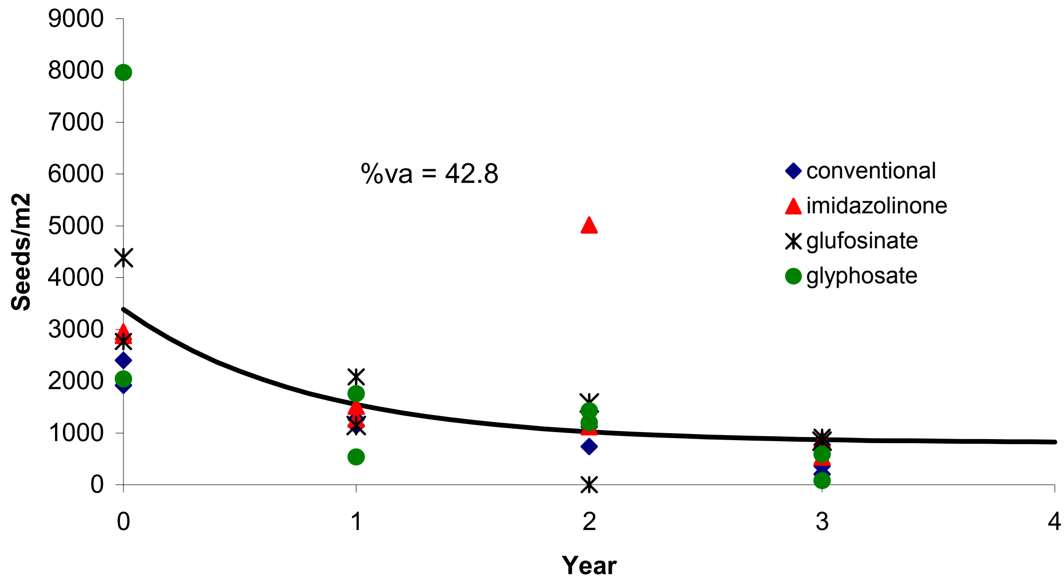

Figure 6.5.3. NIAB, Rotation 3: modelled declines of the seedbanks of the four rape cultivars from the initial seed shed in summer 1999 and for the following three seasons.

Morley - Rotation 3

Again there were no significant differences between the four cultivars but unlike the previous three sites the asymptote was (mathematically) less than zero and no seeds were predicted to remain after 3.5 years (Table 6.5.1, Fig. 6.5.4). The decline in the first season was relatively slow, as the site manager deliberately endeavoured to maximise the incorporation of the seeds into the seedbank by ploughing immediately after harvest. The reason for the rapid decline in the seedbank in the subsequent years is not clear, but this site had the lightest soil and previous work on the persistence of rape seeds had indicated greater persistence on heavy soils (Lutman *et al.,* 2003).

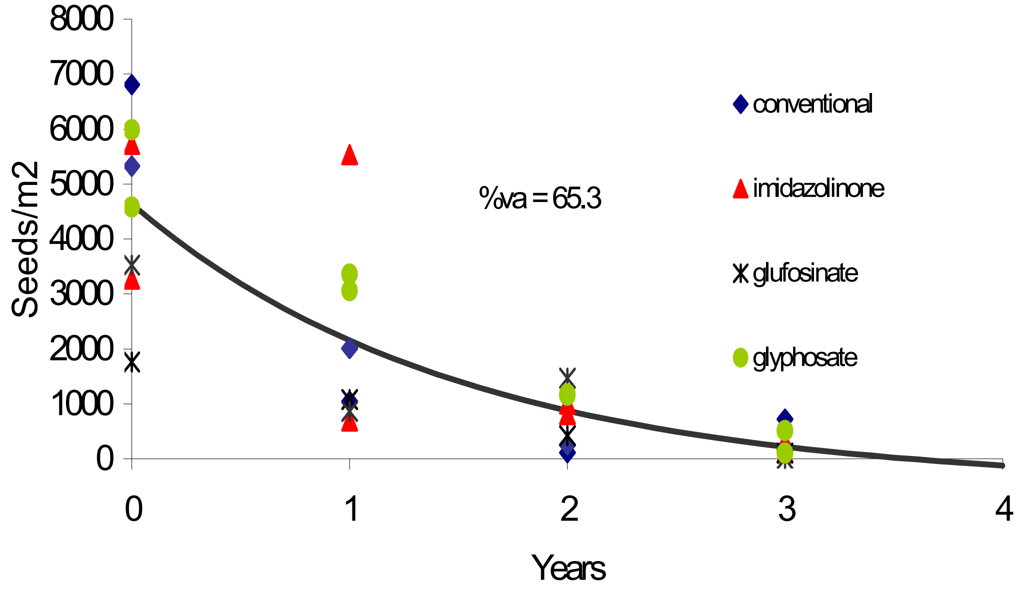

Figure 6.5.4. Morley, Rotation 3: modelled declines of the seedbanks of the four rape cultivars from the initial seed shed in summer 1999 and for the following three seasons

Conclusions

The regression analyses at three of the four sites showed that appreciable numbers of seeds were surviving into the fourth season and indicated that many of these would survive for a considerable time thereafter. As there was only a maximum of 3 year's data on the persistence of the seedbank it is not possible to define the asymptote (A parameter) very accurately. The shape of the end of the decline curve is not well predicted. More samples in subsequent years would be needed to confirm the shape of the exponential decline curve. The exponential model did not fit the SAC data because there was little evidence of seed numbers declining after the initial losses (Fig. 6.4.1). This may have been 'real' or may have simply been a result of the variability in the data (which was also a problem at Broom's Barn). Further years' data would have been needed to record subsequent declines. Data from Rotation 4 could not be used in the regression model as there was only three years' data (the WOSR was sown in Year 2). Other studies at Rothamsted (Lutman *et al* 2003) indicated that 95% of seeds would disappear in 3-4 years but in the BRIGHT experiments it appears that survival will be longer. Further confirmation of the longevity of the seeds comes from some of the sites that we could not use for the regression analyses.

Where cultivar differences were detected the conventional cultivar Apex tended to have the highest asymptote, and there was no indication that the herbicide tolerant cultivars were more persistent than the conventional ones. Interestingly at NIAB the other conventional cultivar Synergy seemed much less persistent than the Apex. This agrees with a previous Petri-dish test by Pekrun *et al*, (1997), which showed Synergy to be less persistent than Apex.

6.6 Petri-dish test of the intrinsic potential of the rape cultivars to develop secondary dormancy

Previous studies have indicated that exposure of seeds to water-stress in the dark can generate secondary dormancy in oilseed rape (Pekrun *et al*., 1997a). These conditions can be simulated in a Petri dish by soaking seeds in polyethylene glycol (PEG), which can generate relevant levels of osmotic pressure. Such a technique was used by Pekrun *et al*., (1997b) for investigating the genetic variability between cultivars and their potential to develop secondary dormancy. This work showed that some cultivars had a greater potential to become dormant than others. More recent work (Lutman *et al.,* 1998; Momoh *et al*., 2002) also indicated that there could also be variation induced by the age of the seeds and the maternal environmental conditions, as seeds from the same cultivar derived from different sources exhibited differing levels of dormancy.

Virtually all the seeds tested in the light in this study germinated, indicating that all were viable. Most seeds germinated after the dark and water stress treatment but a minority remained dormant. The conventional cultivar (Apex) seemed to generate more dormant seeds than the other three cultivars (Fig. 6.6.1). This is in accord with previous work that indicated that Apex tended to be more dormant than most other cultivars. The Brooms Barn seeds were less dormant than the Rothamsted ones but the pattern of response was similar.

Conclusion

The herbicide tolerant cultivars seem potentially marginally less dormant than the conventional variety Apex and therefore should be less persistent in the field.

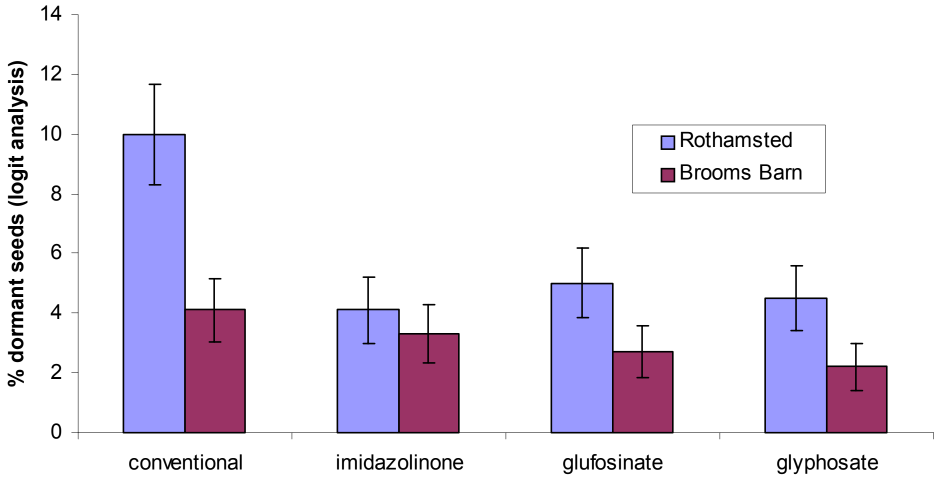

Figure 6.6.1 Percentage dormant seeds (logit transformed) from Rothamsted and Brooms Barn resulting from exposing the seeds to water stress and darkness for four weeks in a Petri dish test. (Vertical bars = 2 x standard errors of means)

6.7 Estimates of the proportion of the rape seedbank that emerges and produces new plants

When the second set of herbicide tolerant crops was planted, the presence of volunteer rape could be relatively easily detected. This was not so simple in the intervening cereal crops, as these crops were often treated with pre-emergence or early post-emergence herbicides and/or the rape emerged quite late in the season. In contrast rape volunteers could be counted prior to herbicide application in the sugar beet crops sown in rotation 3, after the rape in year 1, and also in some of the plots of the second rape crop in rotation 1. In this rotation volunteers that were of a different cultivar could be counted after the herbicide was applied. The dead rape plants could be easily recorded in, for example, plots treated with glyphosate in year 4 that had been sown with glufosinate, conventional or imidazolinone rape in year 1(see Plate 6.2.1). Assessments were made in the rape in year 4 at NIAB, Rothamsted and the Scottish Agricultural College and at Brooms Barn in the sugar beet in year 3. Assessments of rape plant numbers were not so successful in the other sites growing sugar beet in rotation 3 because of the timing of the herbicide treatments, especially on the conventionally treated plots. These counts of volunteer rape could be compared with the rape seedbank recorded the previous winter, thus giving an estimate of the proportion of the seedbank that emerged as new plants in the following season.

Rothamsted - Rotation 1, year 4

In this experiment an appreciable emergence of volunteer rape was observed on the plots treated with glyphosate and glufosinate (where the previous rape crop had been a dissimilar cultivar). There was a strong relationship ($R^2 = 0.61$) between seedlings killed by the glyphosate or glufosinate in the 'dissimilar' data set and the seedbank (Fig.6.7.1). Seedlings represented approximately 1% of the seedbank. Where glyphosate was applied to glyphosate resistant volunteers there was no relationship with the seedbank, but a small percentage of rape seedlings were killed (0.9 plants/m^2). Although there are only four points on the response of the putative glufosinate resistant rape to glufosinate, there was a strong correlation with the seedbank, though the slope of the line was lower.

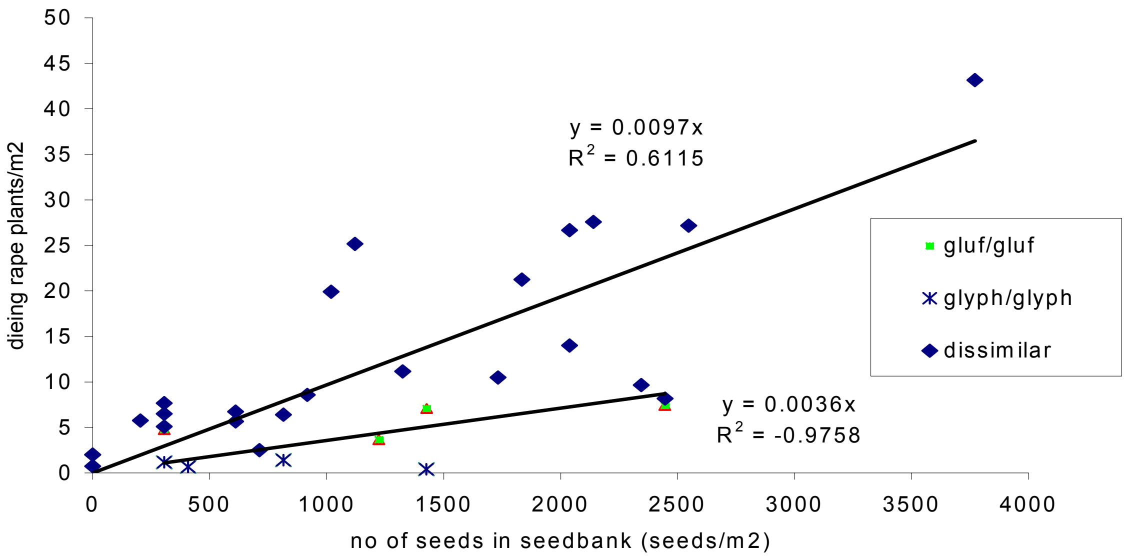

Figure 6.7.1. Rothamsted, Rotation 1: Relationship between the rape seedbank in winter 2001/02 and the number of susceptible rape plants (volunteers) detected post-treatment with glyphosate or glufosinate in year 4 (November 2001) (dissimilar = glyphosate/glufosinate treated in year 4, preceded by one of the other three cultivars in year 1: glyph/glyph = glyphosate resistant rape in year 1 followed by glyphosate treatment in year 4; gluf/gluf = glufosinate resistant rape in year 1 followed by glufosinate treatment in year 4)

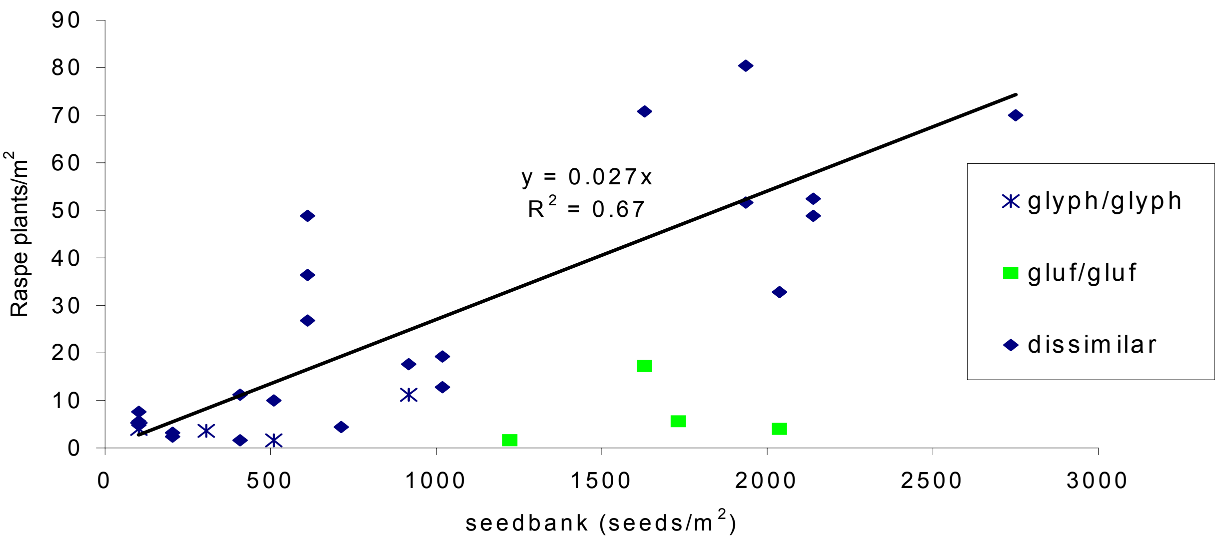

Figure 6.7.2 Scottish Agricultural College, Rotation 1: Relationship between the rape seedbank in winter 2001/02 and the number of susceptible rape plants (volunteers) detected post-treatment with glyphosate or glufosinate in year 4 (November 01) (dissimilar = glyphosate/glufosinate treated in year 4, preceded by one of the other three cultivars in year 1. glyph/glyph = glyphosate resistant rape in year 1 followed by glyphosate treatment in year 4; gluf/gluf = glufosinate resistant rape in year 1 followed by glufosinate treatment in year 4)

Scottish Agricultural College - Rotation 1, year 4

A similar pattern of responses is presented from the Scottish Agricultural College site. Where the herbicides were dissimilar to the volunteers present on the plots, there was a clear correlation between seedling numbers killed and the seedbank that winter (r^2=0.67) (Fig. 6.7.2). However, the slope of the line was steeper than at Rothamsted, with approximately 2.7% of the seedbank being present as seedlings.

Where glufosinate was used to treat apparently glufosinate resistant volunteers there was not much evidence of a link with the seedbank but a small number of susceptible plants were recorded (7 plants/m^2). Where glyphosate followed glyphosate approximately 5 plants/m^2 were resistant, but again there was no obvious link to the seedbank.

NIAB - Rotation 1, year 4

There were fewer plots on this experiment and so the comparison with the seedbank is less clear. However, when the plots had a dissimilar history there was a weak relationship between killed seedlings and the seedbank (r^2 = 0.47) (Fig. 6.7.3). The slope of the line indicated that approximately 1% of the seedbank had emerged. A few glufosinate susceptible plants were detected on the glufosinate treated plots (2.7 plants/m^2) but virtually none on the glyphosate followed by glyphosate plots.

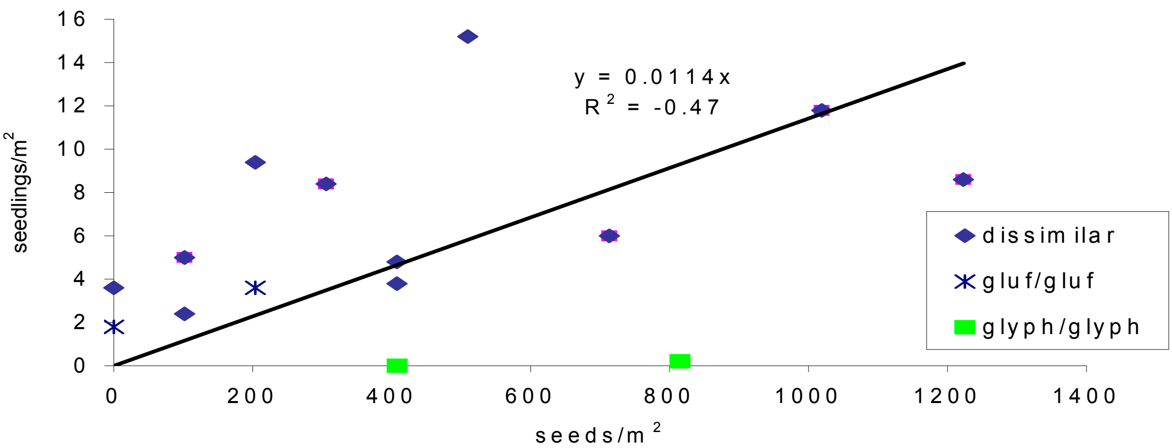

Figure 6.7.3 NIAB Rotation 1: Relationship between the rape seedbank in winter 2001/02 and the number of susceptible rape plants (volunteers) detected post-treatment with glyphosate or glufosinate in year 4 (November 01) (dissimilar = glyphosate/glufosinate treated in year 4, preceded by one of the other three cultivars in year 1. glyph/glyph = glyphosate resistant rape in year 1 followed by glyphosate treatment in year 4. gluf/gluf = glufosinate resistant rape in year 1 followed by glufosinate treatment in year 4).

Broom's Barn - Rotation 3, year 3

At this site the numbers of rape volunteers were counted prior to herbicide treatment, so it is not possible to compare the origins of the volunteers, as was done in the rotation 4 experiments. There was a good general relationship between the seedbank and seedling numbers but it tended to be curved, with fewer seedlings present than expected at the higher densities in the seedbank (Fig. 6.7.4). The reason for this is not clear. If the four highest values are excluded a good linear trend is apparent between seedlings and seedbank (y = 0.050x: r^2 = 0.81). Thus at these lower levels approximately 5% of the seedbank was present as seedlings, higher than in the rape studies in rotation 1.

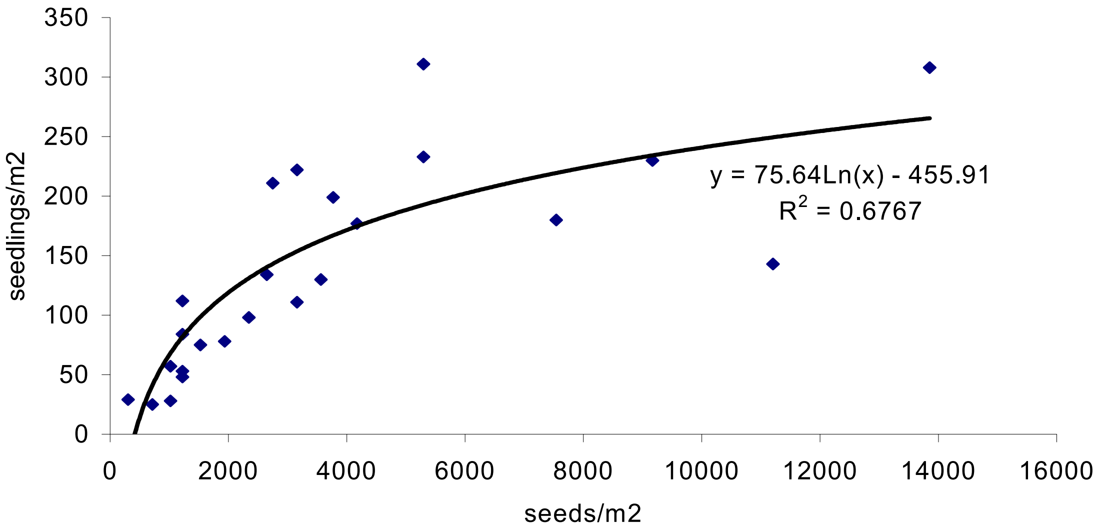

Figure 6.7.4 Broom's Barn, Rotation 3: Relationship between the number of rape seedlings present in the sugar beet crop in 2001 and the rape seedbank measured in the previous winter

Conclusions

At Morley and NIAB in Rotation 3 there was variation in the treatment timings and assessment dates of the volunteers in relation to the treatments and so it was not possible to collect reliable data on volunteer rape numbers. Some of the conventional treatments were applied pre-emergence of weeds which reduced the rape seedling emergence. In the glyphosate and glufosinate plots the pre-treatment counts were not always done at the same time which again influenced numbers present. Hence for rotation 3 only one site was considered appropriate for this particular study.

In the studies of the killed volunteer rape in the rape crops of rotation 1, where the crop sequence was dissimilar, approximately 1% of the seedbank emerged at two sites and nearly 3% at the third. At the sugar beet site (Broom's Barn) seedlings represented about 5% of the seedbank. Thus, overall it appears that 1-5% of the seedbank emerges each year.

The presence of a small number of susceptible seedlings where rape plants from glyphosate tolerant rape were treated with glyphosate, indicates that either there may have been transfer of seeds from plot to plot at harvest or during subsequent cultivation, or that there was a low level of susceptible seeds in the planted sample of glyphosate tolerant rape.

When glufosinate rape followed glufosinate rape at Rothamsted there were more susceptible seedlings and an indication that the numbers were linked to the seedbank. There were susceptible seedlings present at the other two rape sites but no link with the seedbank. Again there may have been movement from plot to plot or a low level of contamination but also it is known that there is some segregation of the glufosinate tolerance gene in the F2 generation so that not all the shed seeds in year 1 would have been tolerant. Beissman *et al.,*2003 estimated that 14% of seeds from self pollinating glufosinate tolerant rape would be non-transgenic. Precise estimates from the BRIGHT sites are difficult to establish, as there were only four data points, but the level of susceptibility detected at Rothamsted, for example, was somewhat higher than 14%, indicating levels of outcrossing.

6.8. Cross pollination between herbicide tolerant and conventional varieties of WOSR in 1999 (Rotation 1 at NIAB, and Rotation 1a and 1b at Rothamsted and the Scottish Agricultural College)

Oilseed rape varieties show a high degree of receptiveness to pollen from other varieties but concentration of pollen and levels of cross pollination have been shown to decline rapidly with distance (Scheffler *et al*., 1993 & 1995). However, studies of long distance movement of oilseed rape pollen have demonstrated dispersal of viable pollen over long distances at low frequencies (Thompson *et al*., 1999).

Both insects and wind are widely recognised to influence the transport of oilseed rape pollen (McCartney & Lacey, 1991; Williams, 1987) although the relative importance of wind and insect pollination still remains unclear. Differences in experiment design, genotypes and environmental conditions have likely contributed to the wide variation in reported gene flow frequencies. In field experiments, the relative size of the pollen source and receptor plots is probably one of the main factors causing variation in results. However, common to all studies is an initial rapid decline in cross-pollination frequency with distance from the source plot.

Studies of cross pollination at Rothamsted, Scottish Agricultural College and NIAB aimed to provide data on the dispersal of trangenes between the plots at these sites. At NIAB, a comparison between two conventional varieties were also made; a varietal association (VA) cultivar which consists of a high proportion (80%) of male sterile plants and a standard open pollinated variety. Simpson *et al* (1999) previously reported that the outcrossing potential of the varietal associations was higher so that greater isolation from GM crops may be needed to achieve required purity thresholds. The proximity of the crops permitted cross-pollination that would produce volunteer populations that were likely to be a mixture of conventional, single and double herbicide tolerant plants. This was used to demonstrate the potential for the formation of a seedbank and volunteers that were mixtures which would emerge in subsequent crops creating a novel weed rape infestations. This was done in order to evaluate the effect these volunteers would have on crop and weed management in subsequent beet and cereal crops in Rotations 1 and 3.

Outcrossing data from plots of conventional and herbicide tolerant winter oilseed rape at NIAB

Rotation 1 experiment for studying outcrossing was laid out as shown in Figure 6.8.1 and described in the Methods.

Plots 1 and 8 of the first year of rotation 1 were split into equal areas of Apex and Synergy. Outcrossing levels in cv. Synergy were the highest over all samples tested from plots growing adjacent to glufosinate tolerant oilseed rape (Fig. 6.8.2). Levels of outcrossing in cv. Apex plot 1 were lower than in cv. Apex plot 8 at the interface with the glufosinate tolerant pollen source (Figure 6.8.3.). This corresponds to the lower levels of outcrossing detected in Synergy plot 1. The steep decline in outcrossing level with distance in the plots of Apex was consistent in both plots and differed from the profile of the decline curve of cv. Synergy.

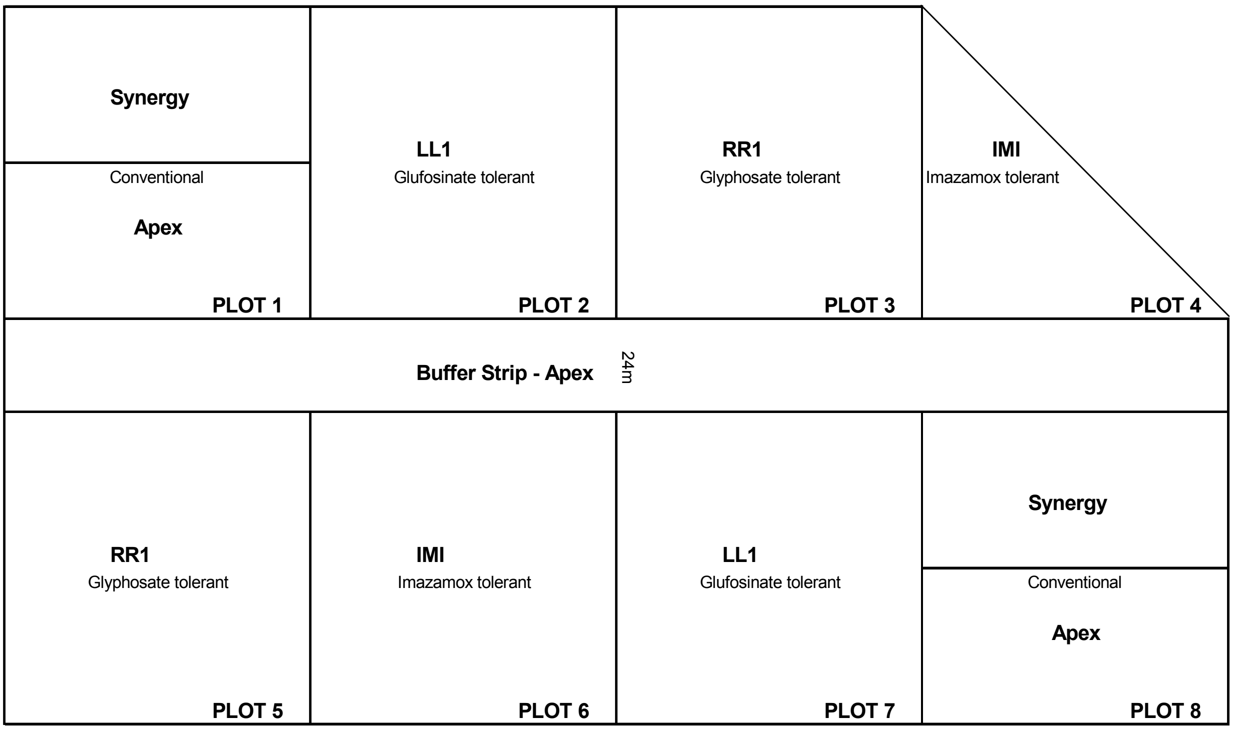

Figure 6.8.1. NIAB Rotation 1. Experimental design. Each plot was 0.8ha (except plot 4 = 0.4 ha) and plots 1 and 8 were split between two varieties Synergy and Apex.

Plate 6.8.1. NIAB Rotation 1. View of Experiment in year 1. Each plot was 0.8ha (except plot 4 = 0.4 ha) and plots 1 and 8 were split between two varieties Synergy and Apex (Plot 8 shown in foreground).

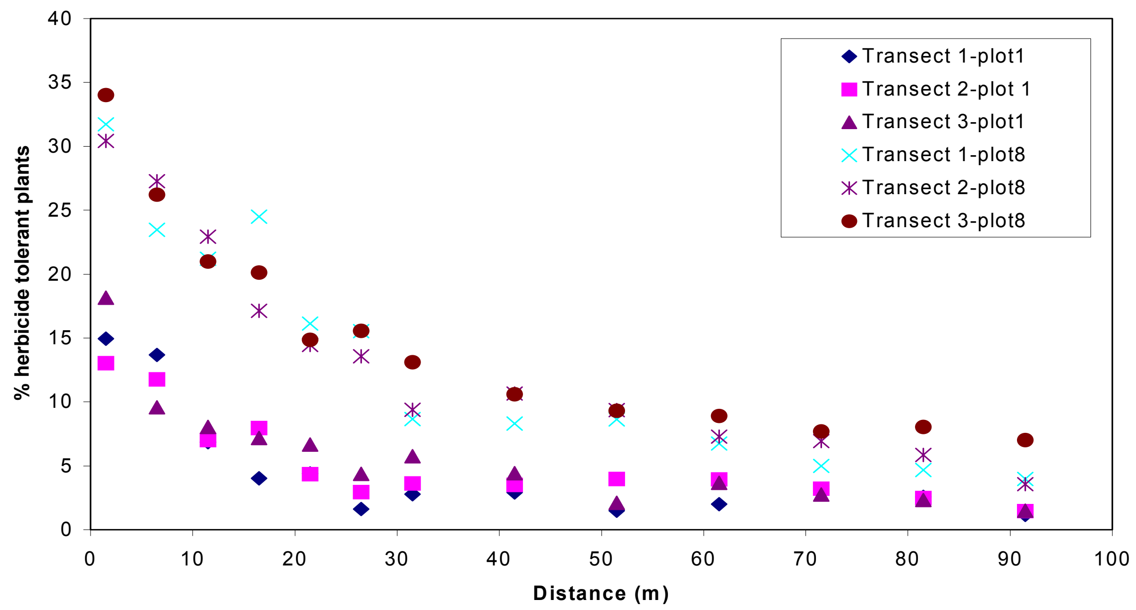

Figure 6.8.2. NIAB : The percentage glufosinate tolerant seeds detected in seed samples from plots 1 & 8 of conventional winter oilseed rape (cv. Synergy) growing adjacent to plots of glufosinate tolerant winter oilseed rape.

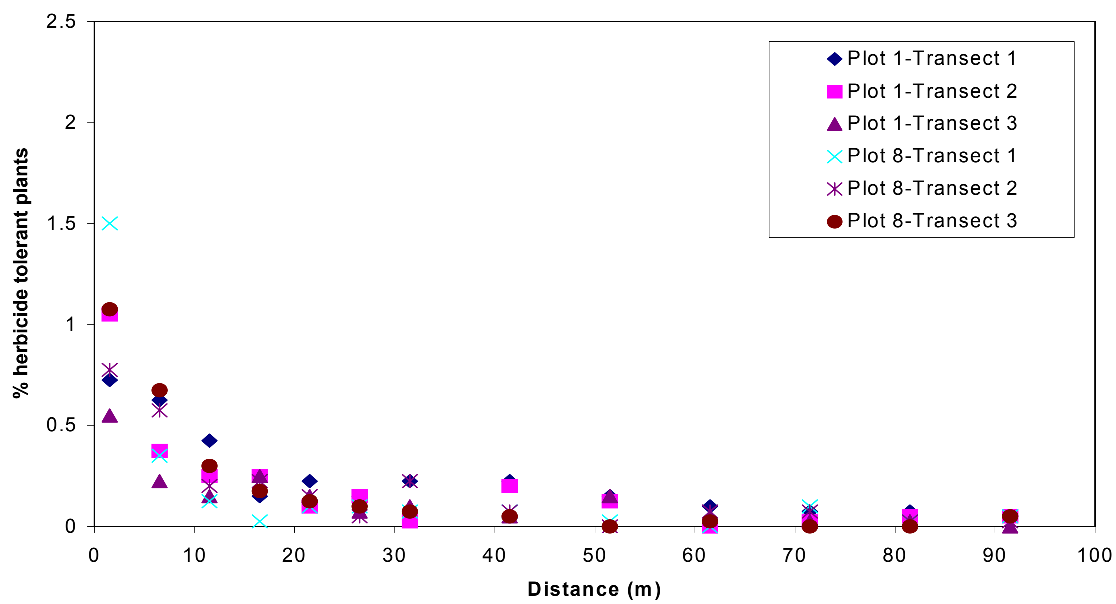

Figure 6.8.3. NIAB: The percentage glufosinate tolerant seeds detected in seed samples from plots of conventional winter oilseed rape (cv. Apex) growing adjacent to plots of glufosinate tolerant winter oilseed rape.

The levels of outcrossing detected in plot 3 (RR, glyphosate tolerant variety) and plot 6 (IMI, imidazolinone tolerant variety) (Fig 6.8.4) were higher over all distances compared to those detected in cv Apex (Fig. 6.8.3) however the decline rate in outcrossing with distance in the GMHT plots was similar to that of cv Apex. Similar low levels of outcrossing were detected at the most extreme sampling point (81.5m), GMHT plots ranged from 0.06-0.1% and Apex 0.03%. The overall mean outcrossing level calculated from all transects, distances and all plots (excluding cv Synergy) was 0.3%. The overall mean from seed samples taken from cv Synergy was 9.7%

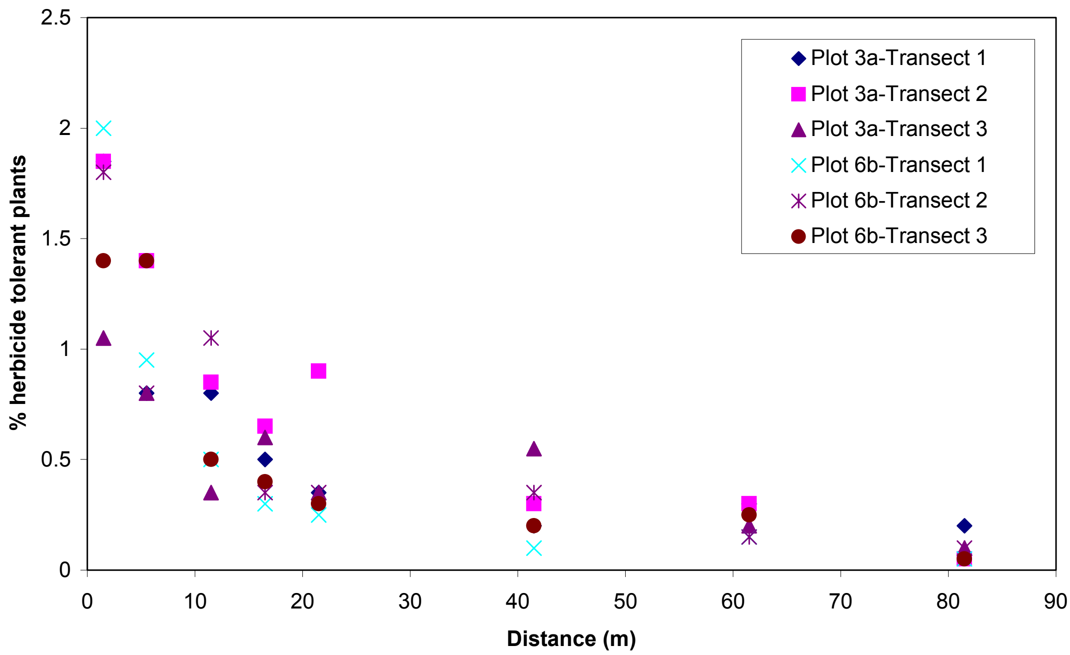

Figure 6.8.4. The percentage glufosinate tolerant seeds detected in seed samples from plots of glyphosate tolerant (cv. RR) and imazamox tolerant (cv. IMI) winter oilseed rape growing adjacent to plots of glufosinate tolerant winter oilseed rape at NIAB.

Outcrossing data from plots of conventional and herbicide tolerant winter oilseed rape at Rothamsted

Examples of outcrossing data from Rothamsted are presented in Figs. 6.8.5 and 6.8.6. Seeds sampled and tested for glufosinate tolerance from plots 13, 14 and 18 are shown in Fig. 6.8.5. Examples of data from glyphosate tolerance tests from plots 5, 6 and 8 are shown in Fig. 6.8.6. Overall, cross pollination levels declined with distance, with values ranging from 0%-4.5% nearest the pollen source and from 0%-1.8% at the furthest sample points. The overall mean across all sample points was 0.9%.

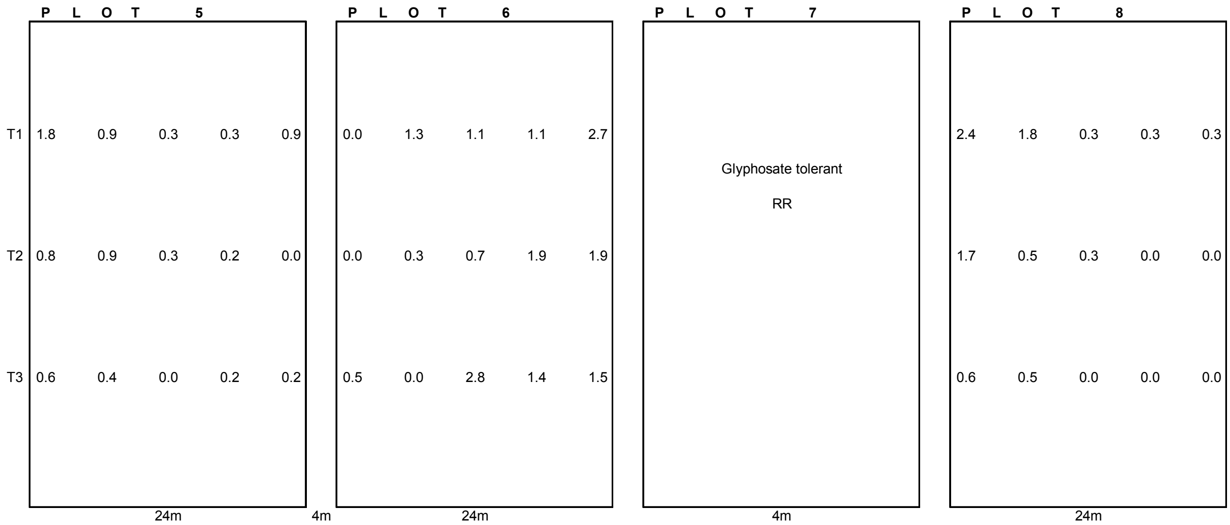

Figure 6.8.5 The percentage glyphosate tolerant seeds detected in seed samples from plots of glufosinate (cv. LL plot 5) conventional (cv. Apex plot 6) and imidazolinone tolerant (cv. IMI plot 8) winter oilseed rape growing adjacent to a plot of glyphosate tolerant winter oilseed rape (cv. RR plot 7) at Rothamsted (T= transect)

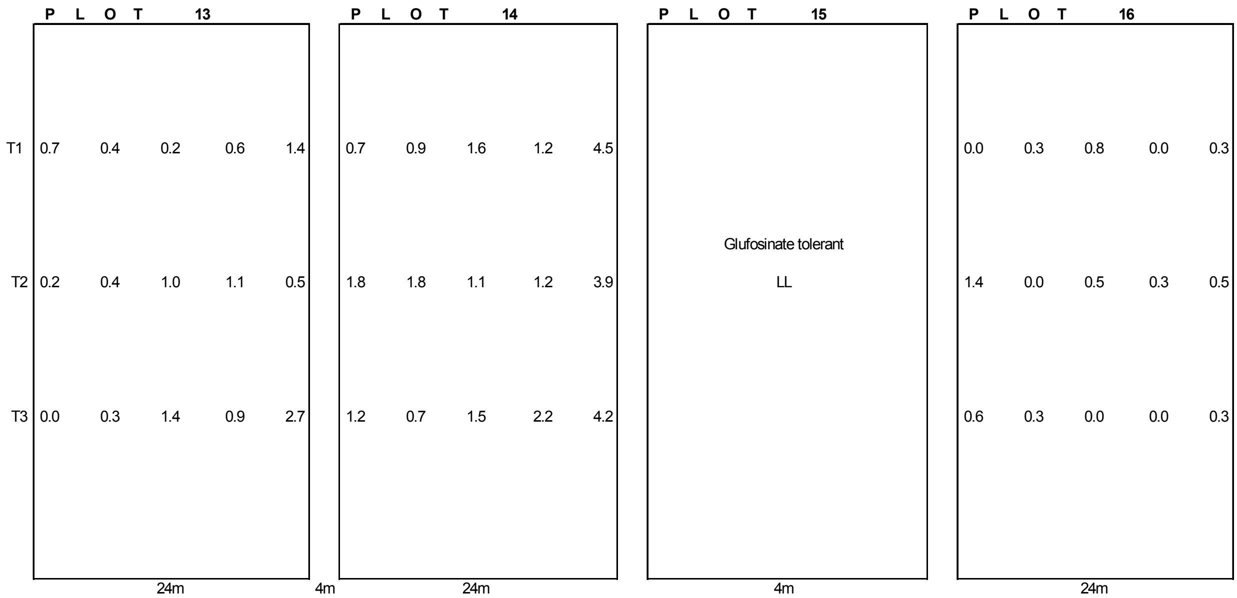

Figure 6.8.6 The percentage glufosinate tolerant seeds detected in seed samples from plots of imidazolinone (cv. IMI plot 13), conventional (c.v. Apex plot 14) and glyhosate tolerant tolerant (cv. RR plot 16) winter oilseed rape growing adjacent to a plot of glufosinate tolerant winter oilseed rape (cv LL plot 15) at Rothamsted (T=transect).

Outcrossing data from plots of conventional winter oilseed rape at Scottish Agricultural College

Examples of outcrossing data recorded at Scottish Agricultural College are shown in Fig. 6.8.7. Levels of cross pollination showed an overall decline with distance although this was less clear in some transects at this site. Levels ranged from 0.3%-4.2% nearest the pollen source to 0.7-4.2% at 20m. The overall mean across all sample points was 0.9%.

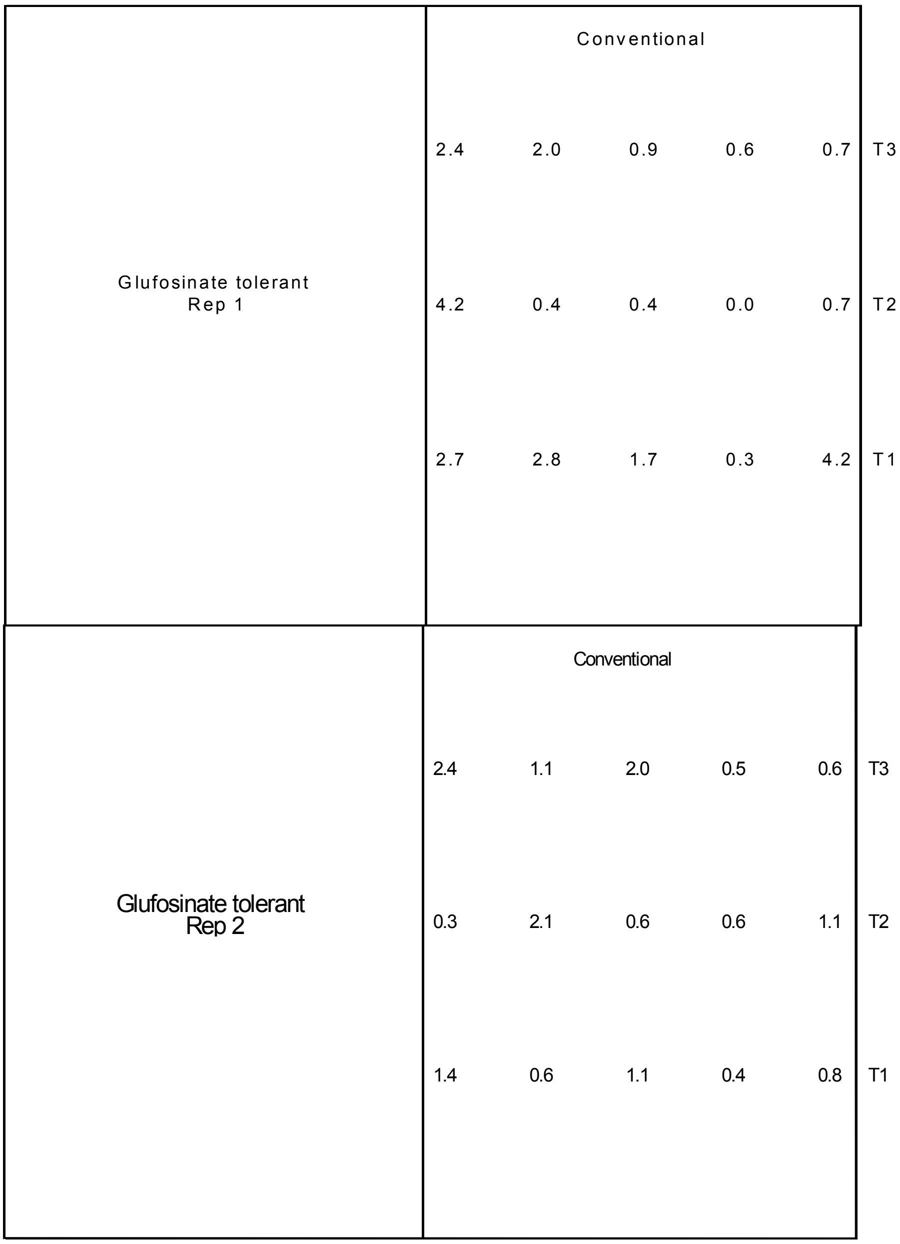

Figure 6.8.7. The percentage glufosinate tolerant seeds detected in seed samples from plots conventional winter oilseed rape (cv Apex) growing adjacent to a plot of glufosinate tolerant winter oilseed rape (cv LL) in replicate 1 and 2 of Rotation 1b at Scottish Agricultural College (T=transect)

Conclusions

The outcrossing data from all sites showed a general decline in levels with increasing distance from the nearest pollen source. At NIAB, where much larger plots were grown, Figures 9.6.1--3 indicate an exponential decline in cross pollination with distance. Both glufosinate and glyphosate were detected at similar levels, whereas imidazolinone tolerance levels were the lowest. It is likely that a combination of factors caused this, the most important being the reduced area (approximately half the area) of the imidazolinone plot 4 leading to a reduction in pollen source size.

At the Rothamsted and Scottish Agricultural College sites, data was comparable to that of NIAB, and showed a decline in cross pollination with distance from the source. Where smaller plots were grown in closer proximity there was considerable "interference" from adjacent GMHT blocks several metres away. This effect can be seen by the cross pollination levels occasionally increasing at greater distances from the source in the same block. This is similar to the results reported by Sweet and Simpson (1999) when studying outcrossing in oilseed rape variety trials conducted by NIAB, which also have small (50 sqm) plots.

The comparison of two conventional varieties "susceptibility" to cross pollination at NIAB showed that the varietal association (VA) Synergy produced much higher levels of GMHT seeds than the open pollinated variety cv. Apex. The level of outcrossing at the most extreme sample distance (91.5m) was nearly 50 times higher than mean outcrossing levels from all other plots crossed with either glufosinate and glyphosate tolerant rape at 91.5m. The differences are due to the high proportion of male sterile plants in varietal association cultivars and thus the reduced competition from self-pollen.

The results also show that varying proportions of seed shed by Apex and the subsequent volunteers would have contained a herbicide tolerance gene. In addition seed shed by herbicide tolerant varieties and the subsequent volunteers would have contained varying proportions with more than one herbicide tolerance gene. The weed control data (Section 5) shows that rape volunteers were controlled in following cereal crops using standard herbicide programmes, there were no instances where populations of rape volunteers survived through to maturity and no indication of changes in sensitivity to the herbicides used on the cereal crops. In Rotation 3 where sugar beet followed GMHT oilseed rape, there were relatively high numbers of rape volunteers surviving or "escaping" herbicide treatments at the three sites. The results of rape volunteer management in sugar beet crops are discussed in detail in Section 5.3.

7. DISCUSSION AND CONCLUSIONS

7.1 Discussions

7.1.1. Overall levels of weed control and performance of the herbicide treatments in the HT crops

Weed control was perceived to be 'acceptable' to the site manager at most BRIGHT sites, on most treatments in most years. At a minority of sites weed control was poor and unacceptable levels of weeds remained. 'Acceptability' is a subjective term and in this case means that weed control was similar to that generally achieved in commercial crops of WOSR and sugar beet, such that the weeds did not threaten crop performance or quality. In the current climate of concern about the impact of farming on agro-ecosystems it could be argued that 'conventional' practice achieves too high a level of weed control. However, it was not the prime aim of BRIGHT to assess whether generally accepted levels of weed control were ecologically sustainable. In this it differs from the Farm Scale Evaluation of GM crops (Squire *et al.,* 2003) which had the target of comparing the ecological impact of growing HT crops and conventional ones. Some information was collected from the BRIGHT experiments relevant to this issue, such as changes in the diversity of species on the oilseed rape rotation (R1) and the change in the weed seedbanks between the start and the end of the project. These studies did not show major declines in either species numbers or seedbanks. It can be argued that a four year rotation with HT and conventional crops, only compared in two of the four years, is not really long enough to detect such changes. Additionally, with the exception of limited data on weed infestation levels on untreated areas in the WOSR and sugar beet, there is no detailed information from BRIGHT on the absolute impact of the treatments on the weed flora. As the trials were primarily agronomic is emphasis, fully randomised untreated treatments were not thought appropriate. Such studies could be considered in future GMHT crop studies and indeed in other work on the impact of crop production / weed control on the weed flora.

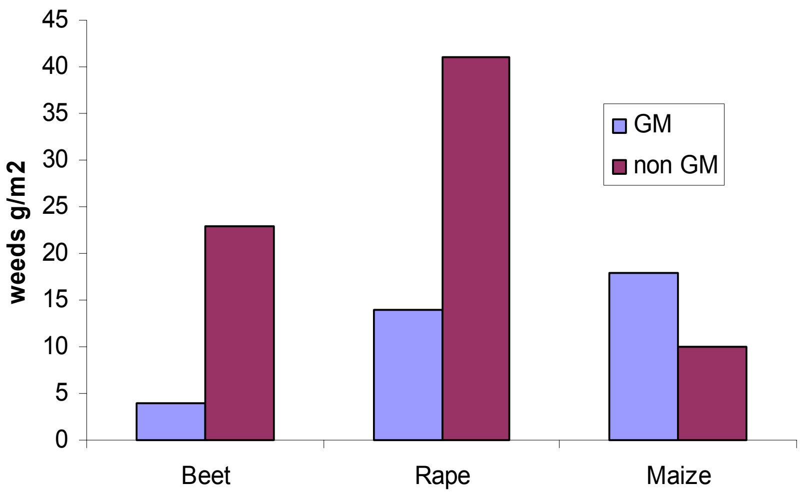

Figure 7.1.1.1 Mean weed levels in mid/late summer for the three crops studied in the Farm Scale Evaluation of GM crops (sugar beet, spring rape and maize) (from Heard *et al*., 2003)

Additionally, changes in weed populations over the rotation (as measured by the seedbank) were also influenced by the overall level of weed control in the non-treatment cereal years. Comparisons of weed biomass in summer, in the different crops in the rotations, clearly show less weed presence in the cereal crops than in the test rape and sugar beet years. 'Crop' had a greater influence on weed levels than 'treatment' within the test years (Fig. 5.1.1.5 & 5.3.1.11) and the conclusions of the other sites in Rotations 1, 2 and 3. Heard *et al*., (2003) reported a similar impact of 'crop' on weed levels in the Farm Scale Trials (Fig. 7.1.1.1).

Performance of the herbicide treatments in the HT crops

This overview is based on data on both total weed densities in spring and total weed biomass in summer. It discusses which treatment either resulted in statistically higher or lower levels of weed control. In most cases there was a close correlation between the treatment responses recorded at both assessments.

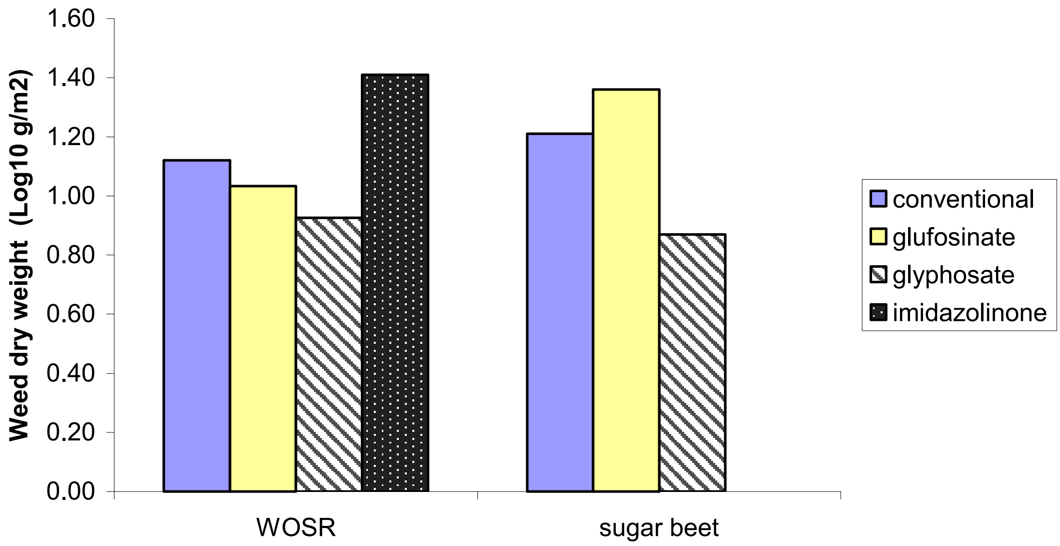

Figure 7.1.1.2 Grand mean of weed dry weights ($\log_{10}$ DM g/m^2) for winter oilseed rape (11 site/years) and sugar beet (5 site/years). (NB Imidazolinone mean is only based on 6 site/years)

i. Oilseed rape

There were twelve occasions when conventional herbicide treatments were compared with glyphosate, glufosinate and the imidazolinone herbicide. On all occasions statistically significant treatment responses were recorded for density and/or biomass. There was trend for the imidazolinone treatment to give the poorest control where it was used (Rotation 1 year 1 and Rotation 4 Year 2) and for glyphosate to give the best control more often than the other two treatments (Table 7.1.1.1). However, all three treatments used in all site/years (conventional, glyphosate and glufosinate) gave the highest level of weed control at some sites in some years. Overall, glyphosate gave the highest control, or shared the best control, at 8 of the 12 experiments. Glufosinate was the best, or shared the highest control on 5 experiments and the conventional achieved the highest (or shared the highest) level of control in 3 experiments. The grand means shown in Fig. 7.1.1.2 confirm these conclusions, with overall lowest weed levels being present on the glyphosate treated plots and most those treated with the imazamox (imidazolinone herbicide). There are few fully comparable WOSR studies with which to compare these results. The programme in Germany reported by Hommel. and Pallutt (2000) and (2003) compared conventional and glufosinate tolerant rape but not glyphosate tolerant. Their work tended to show no marked difference in performance between the conventional and glufosinate treatments. Read & Ball (1999) showed significantly higher weed control with glufosinate than a conventional treatment based on metazachlor and quizalofop. This was most apparent on certain weeds such as *Papaver rhoeas, Capsella bursa-pastoris* and *Aethusa cynapium*. Both treatments had a tendency to give poor control of *Viola arvensis*. The BRIGHT studies also picked out the low efficacy of glufosinate on this weed. A glasshouse and field study in the USA (Hoss *et al.,* 2003) on the relative performance of glyphosate, glufosinate and imazethapyr (same herbicide group as the imazamox used in the BRIGHT WOSR experiments in year 1) on a range of weed species, concluded that glyphosate was somewhat more effective than the other two, a conclusion borne out by the BRIGHT studies.

Table 7.1.1.1 Comparison of the most and least effective weed control treatments used at all sites and years growing winter oilseed rape

Site	Rotation	Year	Significantly more effective	Significantly less effective	Statistical significance
Rothamsted	1	1	glyphosate	imidazolinone	**
Rothamsted	1	4	glyphosate		***
SAC	1	1	glufosinate	imidazolinone	***
SAC	1	4	glufosinate		*
NIAB	1	1	glyphosate	conventional imidazolinone	*
NIAB	1	4	conventional		**
NIAB	3	1	glyphosate		**
Morley	3	1	conventional		*
Broom’s Barn	3	1		conventional	**
Rothamsted	4	2	glyphosate	imidazolinone	***
NIAB	4	2		imidazolinone	***
SAC	4	2	glyphosate glufosinate	imidazolinone	***

ii. Sugar beet

This crop was grown less frequently in the BRIGHT experiments than oilseed rape and 6 comparisons were made of the performance of the varieties. As with the winter oilseed rape the assessments were based on total weed numbers in spring and/or total weed biomass in summer. At the Broom's Barn site differences between treatments were small and it was only in one experiment that a significant treatment difference was recorded (Table 7.1.1.2.). In general, weed control at this site was high. At the other sites there was no clear pattern of responses. However, there was a tendency for glyphosate to be more effective but it was only clearly the best treatment at Morley in Rotation 3. This conclusion is confirmed by the grand mean weed biomasses calculated in Fig. 7.1.1.2, where weeds after glyphosate had a lower biomass than those after the other two treatments.

Table 7.1.1.2 Comparison of the most and least effective weed control treatments used at all sites and years growing sugar beet

Site	Rotation	Year	Significantly more effective	Significantly less effective	Statistical significance
Broom's Barn	2	1		No clear differences	
Broom's Barn	2	4		No clear differences	
Morley	2	4		glufosinate	**
NIAB	3	3		No clear differences	
Morley	3	3	glyphosate		***
Broom's Barn	3	3		conventional	**

Weed control in HT beet has been studied elsewhere over the last few years. Paired comparisons between glyphosate (2-3 applications) and conventional herbicides (up to 4 products), and between glufosinate (2-3 applications) and conventional herbicides, in sugar beet in Germany (Buckmann *et al.,*2000) demonstrated high levels of weed control from all treatments, a feature that concurs with some of the BRIGHT beet data. There was also some evidence that the activity of glyphosate was less variable than the other two treatments, which was associated with the higher level of control. Strandberg *et al.*(2002) compared the performance of glyphosate and conventional herbicides on weeds in fodder beet at several locations in Denmark. They found that the glyphosate treatment achieved a similar or higher level of weed control to the conventional. This conclusion is similar to that of the Farm Scale Evaluation of glyphosate tolerant beet (based on 62 sites) which indicated lower levels of weed control on the conventional plots (Heard *et al*., 2003) (Fig. 7.1.1.1). In an American study (Wilson *et al,* 2002) two applications of glyphosate gave marginally better control than three of glufosinate, whilst three applications of a four product conventional mixture was as good as the glyphosate programme. Virtually all treatments achieved more than 85% control. The above comparisons of relative performance of products in sugar beet are particularly complex to interpret, as the numbers of applications and doses of glyphosate and glufosinate vary and the conventional treatments could be groups of many products applied on several different occasions. This makes a rigorous comparison of the effects of specific treatments very difficult. Overall, levels of weed control in beet tend to be high and there is some evidence that the HT treatments can be somewhat more effective, a conclusion which mirrors the results from the BRIGHT experiments, and those of the Farm Scale Evaluation (FSE). However, the differential between the conventional and glyphosate treatments in the two programmes is lower for BRIGHT than it was in the FSE, as in the former the conventional had less weed and the glyphosate treated plots more weed than in the latter (Figs 7.1.1.1, 7.1.1.2 – detransforming the latter data).

iii. Timing of weed control

One of the main claimed advantages of the HT crop technology is the increased flexibility in timing of weed control. For example, many conventional herbicide treatments in WOSR, and virtually all those in sugar beet, have to be applied either pre- or very early post-emergence to germinating or emerging weeds. In contrast, it is claimed that both HT products are effective at controlling weeds at later growth stages. This applies particularly to glyphosate. In the BRIGHT experiments applications of glyphosate and glufosinate were generally 4-6 weeks later in the beet and 2-8 weeks later in the WOSR than the conventional treatments. Despite these delays they achieved weed control levels similar to, or better than, conventional treatments. Read & Ball (1999) and Hoss *et al.,* (2003) showed that glufosinate tended to be less active on larger weeds, indicating that control should not be delayed too long. Indeed the recommendations for treatment from the manufacturer supported the view that for some weeds, particularly the grasses, the product should be used whilst the plants were small. The weakness of glufosinate on large plants of some species was shown in the BRIGHT trials as overall there were more applications/site/year of glufosinate than glyphosate. The absence of any persistence in soil from both HT products means that the application must not be too early, otherwise later emerging weeds will require subsequent treatment. This problem was demonstrated in the WOSR at the NIAB site (R1 in year 4), where early treatment to control volunteer cereals failed to control a subsequent infestation of *A. myosuroides* (black-grass). A further consideration is that because these herbicides are foliar acting, if applications to beet and WOSR are left too late, the crop has the potential to shade the weeds, thus reducing weed control. This was not specifically demonstrated in BRIGHT but was taken into consideration when deciding on timing of applications.

Finally, the longer weeds are left in the crop, the greater their potential to reduce yields even if they are subsequently controlled. This has been studied in associated work with both WOSR and beet. Studies at Rothamsted in WOSR (Freeman & Lutman, 2004) have shown that with volunteer cereals, delaying control into the late autumn can jeopardise yields but with broad-leaved weeds, control could even be delayed until the spring. Work reported by Dewar *et al.* (2000) indicated that weed control in beet could be delayed until

June (up to 8lf stage of beet). All beet in the BRIGHT sites were sprayed before mid June and all the WOSR before the end of November (except Broom's Barn, Rotn 3, Year 1).

iv. Rotational implications of weed control in HT crops

In the BRIGHT project the herbicide treatments used in the cereal years (ie when the GMHT crops were not grown) were applied uniformly to all treatments. This was done so that the impact of the first GM or conventional crops could be compared directly with the ones sown later in the rotation, without any added complications arising from variable weed control imposed in the cereal crops. However, in farming practice the levels of weed control in the WOSR and sugar beet would impact on the weed control decisions in subsequent crops. It has been suggested that the potential to achieve high levels of weed control in the HT crops would result in reduced weed control in preceding and/or succeeding crops. This was not explored in BRIGHT, though the importance of managing volunteer rape was studied. One particular advantage afforded by the in crop use of glyphosate is the control of perennial weeds such as *Elymus repens* (common couch), *Cirsium arvense* (creeping thistle) and ground keeper potatoes. Although they occurred, these were not major components of the flora at any of the BRIGHT sites. However, it is in these situations that glyphosate could be expected to exert longer term control of weeds in subsequent crops. In addition, enhanced control of volunteer potatoes could reduce the build up of nematodes and sources of potato blight (*Phytophthora infestans*). This component of HT crop management would be a highly relevant area of research that would merit study once GMHT crops are commercialised.

There was only limited evidence from the BRIGHT data of 'carry over' effects, such as effects of Year 1 treatments on the weed flora when the second GM crop was sown in years 3 and 4. This lack of response could be linked to the use of ploughing as the prinmary cultivation technique for all the BRIGHT sites. If non-inversion cultivations had been used it is possible that greater carry over effects would have been seen in the subsequent cereal crop(s). As any major differences in seed return would have been much reduced by the impact of ploughing burying the seeds after the harvest of the GM crop in year 1 and then only returning a proportion of those seeds to the surface in year 3. Carry over effects were noted for example in Year 3 at SAC in Rotation 1 and at NIAB and Broom's Barn in Rotation 3. There was much debate at the planning state of the BRIGHT project about the need to compare different types of primary cultivation. It was highlighted as a serious issue. But having weighed up the benefits of for example splitting the plots into two contrasting cultivation practices (ploughing vs non inversion cultivation) it was decided that the main goals of BRIGHT would be better met by not further reducing the sizes of the plots. It was felt that the project would not deliver its agronomic goals if the plots on the main rotations 1-3 were reduced from the target of about 0.05 – 0.1 ha. The issue of cultivation effects was particularly relevant to the persistence of volunteer rape but it was decided that this issue was being studied in other research programme already in progress, using non GM cultivars (eg. Pekrun *et al.,*1998).

7.1.2 Overview of weed seedbank data

The weed seedbank data were rather variable, but nevertheless overall trends were apparent. Seed assessments based on wet sieving, seed extraction and identification are laborious and so only modest amounts of soil can be processed. However, it offers a major advantage over the seed germination technique in that a very high proportion of the seed present is detected. The seed germination technique, where seeds are germinated in soil placed in pans, presents a major problem. How long do you leave the seeds to be sure of full germination? Published data varies from several weeks to several years! Because of time constraints on the project the latter technique was not an option. Other studies have compared the two techniques some, such as the work of Ball & Miller (1989) have found little difference between the two techniques but others such as that reported by Marshall & Arnold (1994) and Barberi *et al.* (1998) found higher total densities from seed extraction. Barberi *et al* concluded that species number was better defined by seed germination whilst overall numbers by seed extraction, with the proviso that problems occurred witrh the identification of extracted seeds of small-seeded species.

Table 7.1.2.1. Changes in the weed seedbank between the start and the end of the project (ie. after 4 years' cropping) on Rotations 1, 2 and 3.

Rotation	Site	Initial seedbank x1000	Final seedbank x1000	Comments
3	NIAB	14.5	19.0	Increase (data variable)
	Broom's Barn	5.4	13.5	Increase (mainly CHEAL: highest on glufosinate plots)
2	Broom's Barn	9.1	22.0	Increase (highest on conventional plots)
1	Rothamsted	2.6	5.8	Increase
	SAC	8.3	89.3	Increase (mainly due to poor weed control in Yr3 barley: highest on glyphosate plots)
	NIAB	3.1	3.9	Increase (greatest on conventional plots)
Mean (excluding SAC R1)		6.9	12.8	

In six of the seven data sets weed seedbanks increased between the start and the end of the experiments (Table 7.1.2.1). In some cases the increases were small (eg NIAB R1), whilst in others they were huge (SAC R1). Because of the variability in the data, it was difficult to identify significant effects of treatments but where effects were recorded no overall trend was apparent across the sites. For example, the greatest increase at NIAB in Rotation 1 was on the conventional WOSR plots, whilst at Broom's Barn in Rotation 2 it was greatest on the glufosinate tolerant sugar beet plots. The massive increase at SAC in Rotation 1 was probably due to very poor weed control in the barley in Year 3. At the other sites seed production by the weeds in the cereal years of the rotations was small, because of the generally much lower weed survival in the cereal crops. Consequently, the increases seen were considered to be primarily due to the levels of weed control in either the sugar beet or the oilseed rape. Ignoring the SAC site, there was tendency for the increase to be greatest on the sites and rotations growing sugar beet and the increases were often due to inadequate control of *C. album*.

The overall trend of increasing seedbanks over the rotations in the BRIGHT trials contrasts with the conclusions of the Farm Scale trials where there was evidence of decreases in the seedbank where HT beet had been grown (Heard *et al*., 2003). The two sets of data are not easily compared, as the BRIGHT trials have compared seedbank levels before and after a four year rotation and the Farm Scale trials only looked at single years. Additionally, the methodologies for measuring the seedbanks were different, seed banks being assessed by germination in the FSE and by extraction in BRIGHT. The overall levels of the seedbanks on the BRIGHT trials were higher than those recorded on the Farm Scale trials, as the means for sugar beet and spring rape in the latter project were around 2000 seeds/m^2. These figures seem somewhat low compared to the general view that weed seedbanks vary in the region of 10^3 to 10^4 seeds/m^2 (Squire *et al.*, 2003). This range equates better with the seedbank levels recorded on the BRIGHT plots. The data from the Boxworth project (Marshall & Arnold, 1994) indicated that seedbanks were in the region of 2000 seeds/m^2, lower than those recorded at the onset of BRIGHT. However, the Boxworth data also showed the potential for a massive increase in the seedbank in autumns following oilseed rape, which was also a feature of BRIGHT. The impact that low levels of weed control can make on the seedbank has been highlighted by Squire *et al.,* (2000), where reduced weed control on two experiments resulted in an increase in the seedbank from 1-2,000 seeds/m^2 to 70,000 seeds/m^2 in five years.

7.1.3 Volunteer rape

i. Rape seed yields and harvest seed losses

The potential for oilseed rape (WOSR) to establish a seedbank and thus provide a method for the persistence of herbicide tolerant rape through a rotation, was predicted from existing data prior to the start of the BRIGHT project (Pekrun *et al*., 1998) and was one of the prime reasons for the project. Over the four years of the BRIGHT project 12 crops of WOSR were sown at the five sites. Yields and post-harvest seed losses were recorded at all of them. Seed yields were in the region of 3.0 t/ha for all four types of WOSR and mean seed losses were 3575 seeds/m^2, which equates to about 5% of the crop. Seed losses ranged from *c.* 2,000 to *c.* 10,000 seeds/m^2. The mean loss of 3575 seeds/m^2 is somewhat lower than results from earlier WOSR seed loss studies which concluded that average losses were in the region of 7,500 seeds/m^2 (Price *et al.,* 1996; Lutman *et al*., 1998), but a value of 5% is frequently quoted as an 'average' seed loss for combinable grain/seed crops. The absence of any clear differences between the cultivars indicated that the insertion of herbicide tolerance genes does not impact on the pod shattering and seed shedding attributes of the cultivars concerned, though such a conclusion would have been better validated if the project could have had access to isogenic HT and non HT lines.

ii. Post-harvest germination of seeds on the stubble

The shed seeds on the soil surface are the starting point for the development of a persistent seedbank. Studies at four sites explored the behaviour of these seeds in undisturbed stubbles. Seeds remained ungerminated until there was appreciable rainfall and seed numbers declined with time at some sites, indicating a level of predation loss probably caused by birds and invertebrates. Germination caused the major loss of seeds. However, these trials did not indicate the minimum rainfall needed to encourage germination as the minimum rainfall between counts was c. 10mm. Previous research (Lutman *et al*., 1998) suggested that perhaps 4mm was adequate to stimulate germination of the majority of seeds, but this conclusion was based on rather limited data and so would benefit from further information. Seed germination is clearly a very important mechanism for minimising seed incorporation into the soil and the creation of long-term seedbanks. But, not all seeds will germinate and even with appreciable rainfall some seeds will survive. How long should rape stubbles be left after rainfall, to ensure full germination and minimal seed survival? The evidence from these assessments is that the seedlings were large enough to count 8-12 days after a significant rain event, so one would assume that a week after rainfall was adequate to ensure germination of most seeds. Agronomic studies indicate that rape seeds emerge about 5 days after drilling, in the presence of adequate moisture and at average late summer temperatures. Allowing 1-3 days for the plants to become established, the 7 days proposed above seems reasonable.

iii. Seed persistence in the soil

Seed persistence was monitored in 11 site/rotation experiments. As identified in the previous paragraphs about 3500 seeds/m^2 were left in the fields after harvest. There was a substantial reduction over the next 4-6 months, such that seed numbers present in the soil the following winter were about 60% less than those present after harvest. Sites where post-harvest cultivation had been specifically delayed, to allow the seeds to germinate, tended to have lower seedbank populations. Subsequent decline rates over the following two or three years were variable (Fig, 6.4.1) but were uniformly lower than in the previous six months.

Statistically significant differences between the treatments were only identified in 9 of 49 site/rotation/years. There was no consistent pattern in the 9 comparisons, as no one cultivar was consistently more persistent. However, where seed losses at harvest were significantly higher for one cultivar, the seedbank of that cultivar remained higher in subsequent years. This indicates that the decline rate of the buried seeds did not differ dramatically between cultivars. Petri-dish studies on the persistence potential of the cultivars used in the BRIGHT project confirmed that the potential persistence of the HT cultivars was no greater than the convention variety (Apex). There was some indication that Apex was more persistent but this response was not clearly recorded in the field studies. Other work has confirmed that the Petri-dish analyses do give a reasonably reliable estimate of the potential of the cultivars to persist in the field (Gulden *et al.,* 2003).

More detailed regression analyses of the data from 4 of the sites with four years' data showed that cultivar differences in seed decline rates were either small or not statistically detectable. Secondly, as the decline curves fitted an exponential model the absolute declines in seed numbers in the later years was small and the models predicted the survival on three of the four sites of over 10% of the original seeds into the fourth season (271 – 911 seeds/m^2) and many would probably survive for several more years. As the experiments had to cease in 2002, further data could not be collected in order to define the tail of this response curve more precisely. However, the plots have been retained at some sites so that it would be possible to collect further samples in later years. The slow decline in the seedbank in later years has already been identified in other research, primarily with conventional WOSR cultivars (Lutman *et al*., 2003, Lutman, 2003). This ability of relatively low numbers of seeds to persist for at least three years has implications for the co-existence of GMHT and non GMHT crops, as 400 seed/m^2 could produce more than enough volunteer plants to impact on the purity of a subsequent rape crop. This issue has been discussed in more detail in Lutman (2003) and in Simpson and Sweet (2002).

iv. Rape seedling emergence from the seedbank

Having determined the number of seeds in the seedbank, the proportion of that seedbank that emerges as seedlings and develops into plants is the next key issue in the potential of WOSR to infest subsequent crops. Limited data were collected on this subject from:

a) all three sites of Rotation 1 in year 4, as the factorial arrangement of the treatments meant that susceptible volunteer rape plants from year 1 emerging in the year 4 WOSR were treated with glyphosate and glufosinate,

b) one of the Rotation 3 sugar beet sites, where the volunteer rape was specifically assessed.

These studies indicated that 1-5% of the seedbank had emerged. More data would be needed to confirm this range but it does concur with the general perception in weed science that approximately 3-6% of the seedbank emerges following cultivation (Roberts & Ricketts, 1979).

v. Overall impact of volunteer rape

In the BRIGHT experiments the management of volunteer oilseed rape did not pose major problems, though it meant that additional herbicide treatments were required in the sugar beet crops in Rotation 3 to control the volunteer rape plants. However, this applied as much to the conventional sugar beet, as it did to the HT beet, where the volunteers contained the same herbicide resistance gene. Clearly, the management of volunteer rape in beet was easiest when the volunteer rape present in the HT beet crops possessed none or contrasting resistances (e.g. glyphosate tolerant beet and conventional or glufosinate tolerant rape).

Control of volunteer rape in the cereal crops was relatively straightforward as the standard herbicides used were effective. However, the propensity for oilseed rape to emerge over a long period meant that on some sites in some years WOSR volunteers emerged in late spring and early summer. These plants were small and did not affect the vigour of the cereals, but as minimal rape seed return was required, a further extra herbicide treatment was sometimes needed. The longevity of a small percentage of the seedbank could be important if the grower wished to move from growing herbicide tolerant cultivars to conventional ones, as the HT volunteer plants would be sufficiently numerous to affect the seed purity of the subsequent rape crop, grown after three years (and possibly longer).

7.1.4 Yields of oilseed rape and sugar beet

No yield comparisons were made in the Farm Scale Evaluation studies and critics have suggested that unrealistic management may have been applied by some farmers. However, on the BRIGHT trials yields were recorded and yields of the HT varieties of oilseed rape and Apex were similar to national yields (3.0 t/ha) (statistics.defra.gov.uk). Even though the glyphosate and glufosinate tolerant rape cultivars were not fully commercial types, overall their yields were not significantly poorer than Apex. Yields recorded in National List and other variety performance trials have also suggested that the different herbicide managements favoured crop performance and did not result in weed populations that adversely affected crop growth (May, 2003).

Yields of sugar beet were lower than national averages in all varieties due to the earlier harvest. If the beet had been harvested in November-December, it was predicted that yields would have been similar to those reported in other trials of these varieties. Thus, beet management could again be considered to be typical.

7.1.5 Economics of HT oilseed rape and sugar beet

One of the main commercial justifications for the development of herbicide tolerant crops is that they reduce the cost of production and thus increase the farmer's profit. It is unlikely that the rapid uptake of these crops in N. America would have occurred if there had not been an economic advantage to farmers, as well as, to the biotechnology and agrochemical companies that developed the genetically modified crops and the herbicides. The closest commercial comparators to the crops likely to be grown in the UK are GMHT oilseed rape (canola) in Canada and maize in USA and Canada. BRIGHT did not include maize, so this discussion will initially focus on oilseed rape. GMHT beet is not as well established as a commercial crop and so there is little worldwide evaluation of its economics.

Herbicide tolerant canola was first planted in Canada in 1996 and by 2003 over 80% of the crops sown carried this trait; the majority were tolerant to glyphosate (48%), whilst 22% were tolerant to glufosinate and 18% to the imidazolinone herbicides (Van Acker *et al,* 2003). Since the introduction of glyphosate tolerant rape over 8M ha have been sown. The Canola Council of Canada assessed the reasons for this endorsement of the technology in a survey in 2000 (Devine & Buth, 2001). The survey concluded that the principal reasons for growers adopting the technology were:

- easier and better weed control (50%)
- higher yields and/or profits (19%)
- better control of grass and broad-leaved weeds (15%)
- lower costs (10%)

The survey also explored production costs for canola and concluded that overall GMHT crops netted the growers an increased profit of $25/ha. This profit came partly from reduced costs of herbicides, $34/ha for HT crops and $56/ha for conventional, giving a saving of $22/ha. In contrast, the seed costs and the technology fee were higher in the HT crops. Growers also achieved increased yields (c. 10%) and less 'dockage' (income reductions due to presence of weed seeds and other material in the harvested rape seeds) in the HT crops (Devine & Buth, 2001). Thus, reduced costs of herbicides tended to be balanced by increased costs of seed (+ technology fee).

A full comparison of the costs and benefits of HT rape and sugar beet is not appropriate for the BRIGHT programme, and indeed was not part of the original submission to LINK, when seeking funding for the project. This is for several reasons. The trials were not designed to explore the economics of production of HT crops and are not really suited to this analysis. For example, the restrictions imposed by Defra on the handling of the harvested rape seeds, meant that it was not feasible to stagger the harvesting of the different rape cultivars and thus some were not harvested at their optimum time. Similarly, with the sugar beet, constraints on production imposed by British Sugar meant that the beet crops were harvested early (generally in August/September) before the roots had reached their maximum weight. Consequently, all the beet yields were lower than those of commercial crops. This constraint also applied to the recently completed Farm Scale Evaluation of HT beet (Champion *et al.,* 2003).

Costs of weed control – oilseed rape

It is possible to compare the relative costs of weed control in the rape and compare expenditure on the HT and conventional cultivars. Most sites used single applications of glufosinate or glyphosate and most used 3 l/ha of both products (Table 4.3.1, 4.3.2). Over the 12 site/rotations where HT rape was grown the cost of treatment with glyphosate was £18/ha and for glufosinate was £40/ha (Table 7.1.5.1). This is based on a current commercial cost of £10/litre for glufosinate and £3.75/litre for glyphosate. An application cost of £6 was added to each treatment. It is possible to purchase 'generic' glyphosate at a lower price than that quoted above for Roundup Biactive. But, as any approval for glyphosate used in glyphosate tolerant crops is likely to be for one of Monsanto's products, the use of their product in these economic calculations was thought appropriate. In the conventional treatments most sites used metazachlor based products for broad-leaved weed control and sometimes included a graminicide for grass weeds. This led to a span of treatment costs ranging from £35/ha for a low rate of metazachlor alone to £100/ha for a high rate of metazachlor with cycloxydim graminicide, giving an average cost of conventional weed control of £60/ha. The focus of the conventional treatments in BRIGHT on these two groups of products reflects current farm practice as the two most widely used groups of products in Great Britain in 2002 were graminicides (302,100 ha) and metazachlor +/- quinmerac (203,800 ha) (Garthwaite *et al.,* 2003).

Table 7.1.5.1. Cost of weed control in winter oilseed rape (£/ha) at seven sites comparing the three weed control systems

Site	NIAB				Rothamsted			SAC			BB	Mor	Mean
Rotation	1	1	3	4	1	1	4	1	1	4	3	3	
Year	1	4	1	2	1	4	2	1	4	2	1	1	
Conventional	71	81	71	71	100	52	56	57	52	52	96	35	60
Glyphosate	17	17	17	17	17	17	17	17	17	17	13	13	16
Glufosinate	36	72	36	36	36	36	36	36	36	36	46	36	40

BB = Broom's Barn Mor = Morley

Thus, weed control in the oilseed rape crops in BRIGHT was cheapest on the glyphosate treatments and most expensive on the conventional. It was possible to save over £40/ha by growing glyphosate tolerant rape. This saving needs to be balanced by the cost of the technology fee and any other surcharge on the seed charged by Monsanto. A recent paper on the economics of HT sugar beet production (May, 2003) anticipated a fee of £20-30/ha. So weed control would still be cheaper for glyphosate tolerant rape.

A technology fee for glufosinate tolerant rape will not be charged by Bayer Crop Science, but it is possible that the seed will be more expensive. At this stage the differential is not known, but assuming the same price of seed, weed control would be £20/ha cheaper in glufosinate tolerant rape.

In general, as stated in Section 5, weed control was acceptable in most of the rape crops and poor weed control was rarely suspected of causing losses of yield. As is shown in Table 7.1.1.1., glyphosate, glufosinate and conventional treatments all gave the highest weed control at one or more sites. Indeed, much weed control research in the 1990s has tended to confirm that yield losses from weeds in oilseed rape were often low, and did not justify the expenditure on herbicides purely to prevent the weeds competing with the crop (Lutman, 1991). For example, research reported by Walker *et al.* (1990) found an average yield benefit from weed control in WOSR in Scotland of 7%. This lack of competition applies particularly to broad-leaved weeds, which tend to be less aggressive than the grass weeds, and were commoner on most of the BRIGHT sites than the grasses. Utilisation of the competitive ability of WOSR to suppress weeds is not easy with conventional herbicides, as many have to be applied pre- or early post-emergence. For these reasons one can conclude that much conventional herbicide use in rape is unnecessary. By contrast, the greater flexibility in application timing afforded by the HT systems means that it would be possible for the farmer to assess the need for herbicide treatment once the crop and weeds were well established, and thus avoid applications where it was not justified by the level of the weed infestation.

Costs of weed control – sugar beet

As there is no widespread planting of HT sugar beet, it is not possible to explore comparisons of weed control in conventional and herbicide tolerant beet on the basis of commercial practice. However, the recently completed Farm Scale trials of GM crops, provides an opportunity to compare herbicide use in conventional and glyphosate tolerant beet at a large number of sites. Additionally, May (2003) has recently published a detailed breakdown of the costs of weed control in this crop. As explained earlier in this section, a full economic evaluation of the costs of production of HT beet is not possible, primarily because of the early harvest of the beet.

The average cost of weed control on the conventional crops was £84/ha, arising from an average of 2.7 applications (Table 7.1.5.2). This is slightly lower than the £100-£120 quoted by May (2003) based on figures from the sugar beet industry. The industry figure includes a significant cost for the control of volunteer potatoes, which were not present in the BRIGHT trials. The number of applications is also somewhat lower than the industry average of 4-5 applications, but this may be associated with the very early harvest. To achieve weed control with the conventional herbicides, eight different products were used, with a maximum of six at any one site. The most commonly used product was phenmedipham, followed by lenacil, ethofumesate and chloridazon (see Appendix 10.1 for details). The farmers in the Farm Scale trials used 3.6 applications/crop (Champion *et al.,* 2003), again slightly higher than the applications on the BRIGHT trials. Both the main sugar beet growing sites in BRIGHT have a strong focus on sugar beet agronomy and so the staff would have been particularly adept at extracting the optimum activity from their herbicide treatments. Cost of control from both the two HT crops was much lower, particularly for glyphosate, where the mean cost was only £21/ha (Table 7.1.5.2.). Even when the technology fee of £20-30/ha is added to the overall costs, weed control in glyphosate tolerant beet is still appreciably lower (c. £30/ha) than the conventional treatments. The cost of the glufosinate treatment (£63/ha) was not much higher than the cost of the glyphosate treatment plus the technology fee. Most sites only applied 3 l/ha of glyphosate once (as Roundup Biactive) (mean/site 3.4 l/ha, applications/site = 1.3), whereas glufosinate (Liberty) was used twice slightly more often (mean applications/site = 1.7) at between 2 and 4 l/ha/application (mean/site = 4.9 l/ha). On the Farm Scale trials glyphosate was applied 1.6 times/site resulting in an overall dose of 4.5 l/ha The somewhat lower use of glyphosate on BRIGHT than in the Farm Scale trials is probably linked to the fact that the herbicide usage on the Farm Scale trials includes pre-drilling treatments (Champion *et al.,* 2003).

Table 7.1.5.2. Cost of weed control in sugar beet (£/ha) at seven sites comparing the three weed control systems (figures in parentheses are the number of applications)

Herbicide	Brooms Barn			Morley			NIAB	Mean
	R2 Yr1*	R2 Yr4	R3 Yr3	R2 Yr1	R2 Yr4	R3 Yr3	R3 Yr3	
Conventional	94 (2)	108 (3)	71 (2)	49 (2)	68 (3)	95 (4)	104 (3)	84 (2.7)
Glyphosate	17 (1)	17 (1)	17 (1)	37 (2)	13 (1)	27 (2)	17 (1)	21 (1.3)
Glufosinate	72 (2)	92 (2)	46 (1)	72 (2)	36 (1)	52 (2)	72 (2)	63 (1.7)

* R2Yr1 = rotation 2, beet sown in Year 1 of project, etc

In both crops and at virtually all sites the conventional herbicide treatments were the most expensive. The glyphosate treatment tended to be the cheapest but as the seed costs and the level of the technology fee are not confirmed it is difficult to establish the precise costs for any future commercial planting. The same uncertainty over seed costs applies to the glufosinate treatment. However, experience from production elsewhere in the world indicates that HT treatments would generally be less costly than conventional herbicide treatments.

A complete economic analysis would need to take into account a range of other factors such as the yield of the varieties, the market price, the costs of any segregation and identity preservation, and costs of processing etc. Tolstrup *et al*. (2003) in their study of the coexistence of GM crops in Denmark, estimated that sugar beet production costs would be reduced by 9.8% in HT crops whereas, manufacturing and processing costs would increase by 2.1%, giving an overall cost reduction of 7.7%. By contrast, they estimated that HT (glyphosate tolerant) oilseed rape production would increase costs by 8% and manufacturing and processing costs by 14%, giving an overall cost increase of 22%.

7.1.6 Impact of weed management systems on invertebrates

The BRIGHT programme focussed on the botanical changes brought about by the contrasting HT and conventional weed control regimes. Although plot sizes were relatively large for agronomic studies they were still at most sites only a maximum of 36m wide for rape and 24m for sugar beet. Such sizes were inadequate for studies of effects of treatments on invertebrates, whose mobility would result in responses on one plot being influenced by adjacent ones. Therefore at the outset of the project it was decided that the focus of the work should be on botanical responses to the treatments, as well as the agronomic consequences.

7.2 CONCLUSIONS

7.2.1 Weed control

a. The glyphosate and glufosinate herbicide tolerance systems studied in BRIGHT were effective and flexible, and achieved similar/higher levels of weed control to the conventional treatments. Overall, glyphosate tended to be most effective, but there were site/years when the other treatments were more active. There was little evidence that the HT systems caused a reduction in the seedbank over the four year rotations involving two HT crops. Nor was there a detectable effect on the species diversity in winter oilseed rape.

b. Timing of the glyphosate and glufosinate in WOSR was much more flexible than that of the conventional treatments for broad-leaved weed control, which tended to be based around metazachlor. They gave better control of larger weeds and thus could be applied later. Conventional treatments either had to be applied pre- or very early post-emergence. This differential was much less acute for grass weed control, where conventional treatments with graminicides were applied later.

c. Timing of the glyphosate and glufosinate applications was again more flexible in sugar beet. The conventional treatments had to be applied pre- and/or early post-emergence in order to achieve satisfactory weed control. Delaying application of glyphosate and glufosinate until June still achieved good weed control and did not apparently reduce yields (yield comparisons are confounded by the different cultivars associated with the different herbicides).

d. Glufosinate was less effective on older weeds, particularly grass weeds, than glyphosate. Therefore, sometimes it had to be applied early more often than glyphosate. Both glufosinate and glyphosate have no soil acting residual activity, so that later emerging weeds are not affected. At some sites, especially in sugar beet, a second treatment was needed, reducing the cost benefit of the HT technology. This problem was less acute for glyphosate as activity was not so affected by weed size. The problem of treating early to control the first flush of weeds and then failing to get the second treatment on was shown in the experiment NIAB Rotn 1. Early treatment for volunteer wheat resulted in plots being heavily infested with later emerging *A. myosuroides*, which in this case was not treated because of excessively wet soil conditions later in the autumn.

e. It is believed that as both glufosinate and glyphosate are only foliar acting, if applications are delayed too long then crop leaves can screen the weeds so that they are shielded from the sprays, giving poorer control. In WOSR cold weather in mid winter often partially defoliates the plants removing the larger, older, more senescent leaves so that spraying can be done at this time. However, it may be too wet then to travel on the land. Most HT treatments were applied in October-November but a few were done in the

WOSR in February, when crop establishment was delayed and weather conditions prevented early winter applications. This potential problem of shading resulting in poor control was not experienced, as these late treatments gave adequate levels of weed control.

f. In WOSR autumn applied metazachlor has soil acting residual activity and can inhibit weed germination for several weeks. By contrast glufosinate and glyphosate have no soil acting residual activity and thus weeds will continue to germinate and grow after treatment. On occasions this resulted in weeds developing under the rape canopy in the HT plots while few weeds grew in the conventional plots (e.g. Morley Rotation 3 year 1).

g. The conclusion from the BRIGHT study is that, despite the flexibility of the glufosinate and glyphosate, both have an optimum application window to achieve good weed control without having to be applied twice (or more). The start of the window depends on the end of weed emergence and the end on the extent of crop ground-cover, which in turn depends on crop vigour driven by crop emergence date and weather. A related issue associated with the latest timing, is the risk of yield losses arising from the competitive impact of the weeds prior to treatment, if control is delayed too long. This could be an issue with volunteer cereals and some annual grasses in WOSR, but is unlikely to be of concern with other weeds. It is also of major concern in sugar beet where very late applications can result in yield losses. This aspect of delayed control was not explored in BRIGHT as, although the applications of the HT crop herbicides were generally 2-8 weeks later than the conventional treatments, they did not exceed the perceived safe latest timings for maintenance of yields.

h. In sugar beet, the BRIGHT trials showed that there is no need to apply pre-emergence herbicides to HT crops and weeds can be controlled at much more advanced growth stages, especially by glyphosate. However, there is also a need to protect young beet seedlings from weed competition in order to achieve rapid crop establishment such that two applications of herbicide to the HT crops were sometimes needed.

i. One of the main benefits of HT technology in beet is the ability to control weed beet with a low cost chemical method. Weed beet now infests 70% of the beet area in the UK and is spreading. The main control methods are inter-row hoeing and intra-row hand rogueing, both of which are time consuming and expensive. High levels of weed beet control were achieved with both glyphosate and glufosinate in Rotation 5.

j. Beet experiments had to be harvested early (September) at the request of British Sugar. This meant that the full effect of the herbicides on the control of late emerging and late season weeds was not evaluated. In some instances additional treatments may have been needed if beet crops were to be harvested in November/December. In addition greater levels of weed seed return may have occurred.

k. Weed species diversity was only assessed in detail in Rotation 1. The weed species surviving a treatment seemed to be more dependant on local conditions, the timing of the herbicide application (and thus weed escape) and survival. Some influence of the active ingredient was observed, for example, where glufosinate gave reduced grass weed or *V. arvensis* control. However, there was no indication that any particular treatment consistently produced a lower number of species either after the first, or, second HT crop comparisons. Therefore there is no indication that any one treatment reduced botanical diversity more than any other. In sugar beet, the numbers of surviving weeds was very low, so no statistical analyses of effects on botanical diversity were conducted in Rotations 2, 3 and 5.

l. Species diversity in WOSR in BRIGHT appeared slightly lower than in the spring rape in the Farm Scale Evaluations but this may have been due to site factors and the difference between winter and spring crops.

m. Little advantage was found in BRIGHT in following one HT rape crop with a rape crop of different sensitivity in order to control weeds. Because of the potential of creating volunteers tolerant to more than one herbicide, which could make their control problematic in subsequent years, it would seem appropriate to stay with the same herbicide tolerance in any one rotation. However, this could encourage the selection of resistant weeds and a build up of HT volunteers. But if rape is only grown one crop in four and appropriate weed management measures are implemented in the other crops in the rotation, new problems should not be created.

n. Post rape harvest weed control in BRIGHT was generally achieved either by cultivation and/or by the use of diquat/paraquat, so that a uniform treatment could be used across the sites. In normal practice glyphosate is extensively used for control of rape volunteers in stubbles, set aside and other parts of the rotation. By contrast glufosinate has only limited usage in other arable crops, mostly in desiccation of potatoes and oilseed rape. Thus, if glufosinate tolerant rape is grown, glyphosate is still available for the desiccation of crops and the control of the volunteer rape in stubbles. Tank mixes of other herbicides with glyphosate could be used to control glyphosate tolerant volunteers but this may not be very practical and will add costs and complexity to autumn operations at a busy time of year.

o. The results showed that HT oilseed rape volunteers could be controlled in beet possessing a different herbicide tolerance. An extra herbicide (metamitron) was added to the herbicide tolerance treatment of the beet to control rape volunteers in beet possessing the same herbicide tolerance. However, the optimum timings/growth stages for the target weeds differed for the two components of the mixture. Thus, growing beet after rape with the same HT characteristics is problematical and can result in weed or volunteer control failures. Further development of appropriate partner products is needed.

p. Beet has poor tolerance of weed competition and thus high levels of weed control are much more important in beet than rape. The conclusion from the BRIGHT study is that in rotations containing both rape and beet it will be more effective to grow crops with different herbicide tolerances in order to facilitate volunteer rape control. The preferred option from BRIGHT would be to grow glufosinate tolerant rape and glyphosate tolerant beet.

q. In cereal crops, the weed control programmes gave good control of HT oilseed rape and beet volunteers. However, in order to ensure that there was no seeding by HT rape volunteers in the cereals and hence carry over into subsequent rape crops, there was greater use of sulfonylureas such as metsulfuron-methyl and other spring herbicides in some of the cereal crops in some years. This would have had an overall negative effect on the weed populations and hence a negative impact on biodiversity in these cereal crops.

7.2.2 Impact of HT crops

a. No direct impacts of the HT varieties or crops (transgenic and non-transgenic) themselves on the botanical diversity or on the agronomic systems studied in these experiments were observed. Although there was no direct comparison of the effects of the HT cultivars on weeds (in the absence of the herbicide), observation of weed and crop growth, and the recorded weed growth on untreated areas (see Appendix 10.3.5) gave no indication that the HT cultivars had affected weed behaviour, directly. The GM varieties had very similar agronomic characters to the conventional varieties used in the study. Early growth of all cultivars was similar. However the non-GM imidazolinone tolerant variety of WOSR had a lower vernalisation requirement than the other varieties and tended to flower and ripen earlier than the other varieties, especially in the trials in England.

b. There was no observed difference in the establishment, vigour and ground cover of the beet and WOSR varieties in this study. Yields were taken to confirm that management of the crops was realistic and in line with acceptable standards. The yields of the varieties and treatments were equivalent to those described in other programmes which have studied these varieties.

c. It appeared that all differences in weed populations and diversity were due to the management of the crops and varieties and not due to their genetic make up.

d. No assessments were done of the effects of the HT crops and their associated herbicides on invertebrates.

7.2.3 Crop Safety and Yields

a. No treatment produced any lasting phytotoxic effects on their respective WOSR types in the BRIGHT experiments. Conventional and glufosinate treatments occasionally caused some transient chlorosis, respectively, on conventional and glufosinate tolerant sugar beet, which temporarily checked their vigour during early growth. Glyphosate produced no adverse effects on glyphosate tolerant beet.

b. Conventional and glufosinate tolerant plants (WOSR and Beet) were sensitive to glyphosate. Conventional and glyphosate tolerant plants were sensitive to glufosinate. The rape variety Apex was tolerant to the conventional selective herbicides used for weed control.

c. In both crops, glufosinate and glyphosate were effectively used to control volunteers, ferals and closely related species. This could be a major advantage in situations where weed beet, feral rape or closely related weeds e.g. other Chenopodiaceae or crucifer species, occur at high levels. But, care must be taken to ensure that the HT traits do not become introduced into these species, by for example, ensuring that HT sugar beet does not flower.

d. WOSR yields were slightly above the national average and indicated that the management used in the experiments was realistic and reflected current practice.

e. Sugar beet yields were lower than average because of the early harvest date imposed by British Sugar to avoid possible mixing with commercial crops. However, yields were still comparable with national averages and indicated that the management used in the experiments was otherwise equivalent to normal agricultural practice.

7.2.4 Gene Flow

a. Outcrossing occurred between plots of WOSR at frequencies that matched those from other studies (Eastham & Sweet 2000). Levels decreased exponentially with distance from pollen source. The varietal association Synergy was pollinated at a higher frequency than other varieties due its low male fertility. Outcrossing between different HT varieties produced seeds with combinations of herbicide tolerance.

b. No hybridisation in beet was possible as reproductive shoots (bolters) were removed from all beet before they flowered, in order to minimise pollen production in the beet experiments. This was a requirement of the Release Consent from DEFRA.

7.2.5. Rotational implications

a. In only a few situations was there an influence of herbicides applied to the first rape crops in a rotation on the weeds and weed control in the second rape crops. This suggested that there is little cumulative effect of the herbicides on weed control. However the research demonstrated some weaknesses, such as grass weeds and *V. arvensis* control by glufosinate, so that it could be anticipated that close rotational growing of glufosinate tolerant rape might result in an accumulation of these weeds. This could be overcome by using appropriate tank mixes and by greater control of these weeds in other parts of the rotation. There was, however, some evidence in the beet studies that poor control of *C. album* in the conventional beet in year 1 was carrying through to influence weed seedbank levels in year 4. It must be pointed out that this conclusion is based on annual ploughing of all the sites. Greater carry over effects might have occurred if non –inversion cultivations had been used as the primary method of soil preparation.

b. It may be possible to reduce levels of weed control in cereal crops in the rotation, as a consequence of good control of problem weeds occurring in the HT crops. This was not explored in the BRIGHT project, and so subsequent rotational studies would be needed to assess this possibility.

c. HT oilseed rape volunteers were controlled in oilseed rape and beet possessing a different herbicide tolerance. Where HT rape volunteers appeared in beet with the same HT then additional herbicides tank mixed with glufosinate and glyphosate were needed to control them.

d. Both glufosinate and glyphosate gave good control of non-HT volunteer and weed beet in respective HT beet crops.

e. In cereal crops, the commonly used weed control programmes gave good control of HT oilseed rape including volunteers with more than one HT trait (as a result of gene flow).

f. At most sites weed control in the years when cereals were sown was greater than in the years when the HT break crops were grown. Weed biomass was often much lower in the cereals than it was in any of the treatments in WOSR and sugar beet.

7.2.6. Volunteer rape

a. Over 3500 rape seeds/m^2 were lost at harvest and remained on the soil surface. As discussed in 7.1.3, seed losses differed slightly between varieties and were not related to yield.

b. The studies showed that GM oilseed rape has similar seed survival characteristics in soil to conventional oilseed rape. Management of the shed seed, seed bank and volunteers post harvest and in intervening crops reduced numbers of volunteers. However, considerable numbers of seeds survived over the 4 year crop rotation (mean 1000 seeds/m^2), supplying a potential source of volunteers to grow and provide admixture in subsequent rape crops. This could pose serious problem with respect to the coexistence of GM and non GM rape crops grown in sequence in the same rotation. Volunteer plants derived from a seedbank of GMHT WOSR at a level similar to that recorded in BRIGHT would result in the subsequent rape crop breaching the EU threshold for the admixture of GM seeds in non GM crop.

c. The recommended procedures for reducing the volunteer rape seedbank: delaying post-harvest cultivation until after rainfall, destruction of germinated seedlings through cultivation or herbicide treatment, destroying volunteers in cereal stubble and control of rape volunteers in cereal crops, all helped to minimise numbers of WOSR volunteers. At Rothamsted and SAC where, delayed post-harvest cultivations were compared to immediate post-harvest ploughing, the seedbank was reduced by the delayed treatment.

7.2.7 Costs of Weed Control

a. The nature and the amounts of conventional herbicide used varied according to local practice and conditions. Similarly, the amounts of glufosinate and glyphosate applied varied according to the weeds present and local conditions. On average the amounts of active ingredient applied to sugar beet were considerably less in the HT treatments than the conventional. This differential was less for oilseed rape, as fewer herbicides were used in conventional rape than in conventional beet. Herbicide use was slightly lower in HT rape than in HT beet,

b. Costs at each site depended on the nature and dose of conventional herbicides and the dose and number of treatments with glufosinate and glyphosate.

c. Preliminary economic calculations indicated that weed control in both beet and WOSR was most expensive at most sites in the conventional crop and was cheapest in the glyphosate tolerant crop (mean costs oilseed rape: conventional £60/ha, glyphosate tolerant £18/ha, glufosinate tolerant £40/ha; sugar beet: conventional £84/ha, glyphosate tolerant £21/ha, glufosinate tolerant £63/ha). The glyphosate treatment remained the least expensive even when the anticipated technology fee from Monsanto was included, though the differential in costs between the glyphosate and glufosinate treatments was much reduced.

8. IMPLICATIONS AND RECOMMENDATIONS.

a. The studies showed that GM oilseed rape has similar seed survival characteristics in soil as conventional oilseed rape. Considerable numbers of seeds can survive over a 4 year crop rotation and probably longer, supplying a potential source of volunteers to grow and provide admixture in a subsequent rape crop. If the subsequent crop is to achieve levels below the EU defined GM threshold of 0.9% in food then careful management of the shed seed, seed bank and volunteers in intervening years is required.

b. The recommended procedures of encouraging shed seed to germinate, destruction of these seedlings through cultivation or herbicide treatment, destroying volunteers in cereal stubble, and control of rape volunteers in cereal crops will help to minimise this potential problem.

c. The herbicide tolerance systems were effective and flexible, and compared very favourably with conventional treatments for weed control, while not apparently decreasing botanical diversity. Glufosinate and glyphosate appear to provide clear economic advantages in beet as well as advantages for weed beet control and control of difficult weeds. Cost benefits also favoured HT oilseed rape, but they were less marked than in beet. The actual cost benefit will depend on a range of other factors such as costs of seeds, technology fees and the value of the harvested crop.

d. Glufosinate and glyphosate treatments and seed costs were anticipated to be less than those of current seeds and treatments in oilseed rape and sugar beet. Hence, farmers would find some economic advantage in using them, particularly on land infested with weeds closely related to the crop, which are difficult or expensive to control, or in situations where it was difficult to use conventional herbicides at optimum times. Calculations by May and Pigeon (2002), which include allowance for a range of other factors also show a strong economic advantage of the HT sugar beet systems. Tolstrup *et al* (2003) calculated the economics of sugar production allowing for segregation of GM and non GM beet and associated produce, through the whole growing, production and processing chain. They showed that while handling and processing costs increased, there was still a net economic benefit from GMHT beet throughout the whole production and processing system.

e. Herbicide tolerance in oilseed rape and sugar beet increases farmers' options for the control of weeds in these crops. They give greater flexibility of timing and management. Using HT crops will have little direct impact on subsequent crops. However, their introduction can create new management issues in subsequent crops of the same species or with the same herbicide tolerance, for example, where GM and non-GM rape is grown in close rotation. These need to be considered carefully when drawing up plans for rotational management.

f. There is also the possibility that use of HT crops could reduce herbicide usage in cereal crops though this aspect was not directly studied in BRIGHT.

g. Increased flexibility of management of HT crops shown in BRIGHT can be used to achieve biodiversity objectives, as has been demonstrated by the studies of Dewar *et al*., (2003) with HT beet at Broom's Barn. It is therefore proposed that further studies are conducted to determine appropriate management strategies for HT crops that will enhance both the economic and the environmental benefits.

h. It is also proposed that oilseed rape seed banks at the BRIGHT sites are studied for at least another three years in order to ascertain likely decline and extinction rates for the GMHT varieties. This information is required for managing the coexistence of GM and non-GM oilseed rape.

i. In these BRIGHT studies the winter cereals often had a greater impact on the surviving weed numbers than the beet or WOSR, irrespective of whether the weed control was conventional or herbicide tolerant. Thus, other aspects of crop rotational management, apart from weed control, can have as great an impact on botanical diversity in arable systems. If biodiversity impact is to be a major factor in decision making on weed control in arable cropping systems, there is a need to look at the subject holistically across crop rotations and address the potential impacts of all crops, not just those potentially including HT systems. We therefore recommend that studies are carried out to assess the biodiversity impacts of all arable cropping systems and methods to alleviate their impacts.

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10. APPENDICES

10.1 APPENDIX 1. HERBICIDES APPLIED TO HERBICIDE TOLERANT CROPS GROWN IN ROTATIONS AT EACH CENTRE.

ROTATION 1

Table 10.1.1. NIAB Rotation 1, Year 1 (1998-1999) : Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Applic-ation date	Crop growth stage at herbicide application*	Main weed sp. growth stage at herbicide application *
CONV	Butisan S	Metazachlor 0.5	2.5	3bar/240l/ha	11.11.98	GS: 1.2-1.3	TRIAE:GS 21, ALOMY: GS 12-13
CONV	Fusilade EW	Fluazifop-P-butyl 0.2	0.75	3bar/240l/ha	11.11.98	GS: 1.2-1.3	TRIAE:GS 21, ALOMY: GS 12-13
LL	Liberty	Glufosinate 0.2	3	3bar/240l/ha	23.11.98		
RR	Roundup Biactive	Glyphosate 0.36	3	3bar/240l/ha	23.11.98		
IMI	Imazamox	Imazamox 0.07	1.75	3bar/240l/ha	23.11.98		

*growth stage at herbicide application or weed assessment timing

Table 10.1.2. Rothamsted Research, Rotation 1a and 1b Year 1 (1998-1999): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Application date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Butisan S	Metazachlor 0.5	2.5	2bar/200l/ ha	28.09.98	GS 1.1-1.3	AVESA: GS 12
CONV	Laser	Cycloxydim 0.2	1.5	2bar/200l/ ha	11.11.98	GS 1.5-1.6	AVESA, PAPRH, VIOAR: 6 leaf
LL	Liberty + Harvest	Glufosinate 0.2 + 0.15	2.4 + 0.6	2bar/200l/ ha	11.11.98	GS 1.5-1.6	AVESA, PAPRH, VIOAR: 6 leaf
RR	Roundup Biactive	Glyphosate 0.36	3	2bar/200l/ ha	11.11.98	GS 1.5-1.6	AVESA, PAPRH, VIOAR: 6 leaf
IMI*	Imazamox	Imazamox 0.07	1.75	2bar/200l/ ha	09.10.98	GS 1.2-1.4	AVESA, PAPRH, VIOAR: 6 leaf

*Only applied to 2 main plots, the other 2 received conventional treatment

Table 10.1.3. Scottish Agricultural College, Aberdeen, Rotation 1a and 1b, Year 1 (1998-1999): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure /volume	Application date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Butisan S	Metazachlor 0.5	1.5	Pressure 130l/ha	6.11.98	GS: 1.2	POAAN: GS 11-12 STEME 2-6 leaf , HORVU, VIOAR, MYOAR, MATsp all at cotyledon - 1 leaf
CONV	Benazalox	Benazolin + clopyralid 30.5%w/w	0.75 kg	130l/ha	6.11.98	GS: 1.2	"
LL	Liberty	Glufosinate 0.2	3	200l/ha	17.11.98	GS: 1.2	"
RR	Roundup Biactive	Glyphosate 0.36	2	200l/ha	19.11.98	GS: 1.2	"
IMI*	Imazamox	Imazamox 0.07	1.75	200l/ha	6.11.98	GS: 1.2	"

*Only applied to 2 main plots, the other plots received conventional treatment

Table 10.1.4. NIAB Rotation 1, Year 4 (2001-2002): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ Volume	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Katamaran	Metazachlor + quinmerac 0.375+0.125	2	2bar/240l /ha	6.09.01	Pre-em	Pre-em
CONV	Laser	Cyloxydim 0.2	1	3bar/240l /ha	25.09.01	GS 1.2-1.3	TRIAE GS12-13
CONV*	Laser	Cyloxydim 0.2	1	3bar/240l /ha	25.09.01	GS 1.2-1.3	TRIAE GS12-13
LL	Liberty	Glufosinate 0.2	3	3bar/240l /ha	25.09.01	GS 1.2-1.3	TRIAE GS12-13
LL	Liberty	Glufosinate 0.2	3	3bar/240l /ha	6.11.01	GS 1.9-1.11	TRIAE/ALOMY GS 22-24
RR	Roundup Biactive	Glyphosate 0.36	3	3bar/240l /ha	25.09.01	GS 1.2-1.3	TRIAE GS12-13

Table 10.1.5. Rothamsted Research: Rotation 1, Year 4 (2001-2002): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure /volume	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Katamaran	Metazachlor + quinmerac 0.375+0.125	2	2bar/220 l/ha	28.09.01	GS 1.1	STEME VERPE VIOAR all cot – 1lf TRIAE GS 11-12
CONV*	Clayton Gazette	Cyanazine 0.5	1	2bar/220 l/ha	20.10.01	GS 1.3-1.5	TRIAE GS 13-14, PAPRH cots-8leaf, VERPE 4leaf
LL	Liberty	Glufosinate 0.2	3	1bar/220 l/ha	1.11.01	GS 1.3-1.5	TRIAE GS 13-14, PAPRH cots-8leaf, VERPE 4leaf
RR	Roundup Biactive	Glyphosate 0.36	3	1bar/220 l/ha	2.11.01	GS 1.3-1.5	TRIAE GS 13-14, PAPRH cots-8leaf, VERPE 4leaf

Table 10.1.6. Scottish Agricultural College Aberdeen : Rotation 1a and 1b, Year 4 (2001-2002): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure /volume	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Katamaran	Metazachlor + quinmerac 0.375+0.125	2	100 l/ha	5.09.01	Pre-em	Pre-em
CONV*	Kerb	Propyzamide 50%w/v	1.4kg	100 l/ha	26.11.01	GS1.4-1.5	STEME , POAAN, MYOAR, VIOAR, MATsp
LL	Liberty	Glufosinate 0.2	3	100 l/ha	26.11.01	GS1.4-1.5	"
RR	Roundup Biactive	Glyphosate 0.36	3	100 l/ha	26.11.01	GS1.4-1.5	"

ROTATION 2

Table 10.1.7. Broom's Barn, Rotation 2 Year 1 (1999): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i/ l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Applic-ation date	Crop GS at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Goltix Stefes Forte	Metamitron 0.7+ Phenmedipham 0.1	1.25kg 1.7	2.2 bar/ 100 l /ha	19.05.99	Cot - 2lvs	Large STEME, VERPE, TRIIN, VIOAR. Cotyledon CHEAL, FALCO, STEME, VIOAR, LAMPU
CONV	Betanal Progress Goltix Shield	Phenmedipham+ Desmedipham+ Ethofumesate 0.06+0.02+0.1 Metamitron 0.7 Clopyralid 0.2	1.5 1kg 0.5	2.2 bar/ 100 l /ha	14.06.99	4-6 lvs	7 cm CHEAL, FALCO, POAAN
LL	Liberty	Glufosinate 0.2	3	2.25 bar/ 200 l/ ha	14.06.99	4-6 lvs	7 cm CHEAL, FALCO, POAAN
LL	Liberty	Glufosinate 0.2	3	2 bar/ 200 l/ha	6.08.99	14+ lvs	Flowering STEME, POAAN, FALCO, CHEAL
RR	Roundup Biactive	Glyphosate 0.36	3	2.25 bar/ 200 l/ ha	14.06.99	4-6 lvs	7 cm CHEAL, FALCO, POAAN

Table 10.1.8. Morley Research Centre Rotation 2 Year 1 (1999): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Applic-ation. date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Pyramin DF Betanal E oil	Chloridazon 0.65 Phenmedipham 0.114+ Oil	0.75kg 1.5 0.5	100 l/ha 4 bar	8/5/99	Just before emergence	CHEAL FALCO POLAV
CONV	Betanal E Goltix WG oil	Phenmedipham 0.114 Metamitron 0.7+ Oil	1.5 1.7kg 2.0	100 l/ha 4 bar	1/9/99	2-6 lvs	CHEAL FALCO POLAV
LL	Liberty	Glufosinate 0.2	3.0	200 l/ha 3 bar	14/6/99	6-8 lvs	CHEAL FALCO POLAV
LL	Liberty	Glufosinate 0.2	3.0	200 l/ha 3 bar	14/7/99	Row closing	CHEAL FALCO POLAV
RR	Roundup Biactive	Glyphosate 0.36	3.0	200 l/ha 3 bar	14/6/99	6-8 lvs	CHEAL FALCO POLAV
RR	Roundup Biactive	Glyphosate 0.36	3.0	200 l/ha 3 bar	14/7/99	Row closing	CHEAL FALCO POLAV

Table 10.1.9. Broom's Barn Rotation 2, Year 4 (2001-2002): Herbicide treatment programme for HT crops.

Treat-Ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Applic-ation date	Crop GS at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Takron	Chloridazon 0.4	2.5	2.5 bar/ 200 l/ha/	30.03.02	Pre-em	
CONV	Mandolin flo + Venzar	Phenmedipham 0.2 Lenacil 0.8	1.7 0.4	2.25 bar/ 100 l/ha	16.04.02	Cot	
CONV	Mandolin flo + Venzar	Phenmedipham 0.2 Lenacil 0.8	1.7 0.4	2.25 bar/ 100 l/ha	24.04.02	Cot - 2lvs	CHEAL, FALCO, SENVU, VIOAR, POAAN
CONV	Twin + Shield	Ethofumesate: Phenmedipham 0.094:0.097 Clopyralid 0.2	2 0.5	2.25 bar/ 100 l/ha	19.06.02	8-16lvs	
LL	Liberty	Glufosinate 0.2	4	2.5 bar/ 200 l/ha	8.06.02	8-10lvs	
LL	Liberty	Glufosinate 0.2	4	2.5 bar/ 200 l/ha	12.07.02	16+ lvs	CHEAL, SENVU, VIOAR, POAAN
RR	Roundup Biactive	Glyphosate 0.36	3	2.5 bar/ 200 l/ha	8.06.02	8-10lvs	

Table 10.1.10. Morley Research Centre, Rotation 2 Year 4 (2001-2002): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ Volume	Applic-ation. date	Crop growth stage at herbicide application.	Main weed sp. growth stage at herbicide application
CONV	Better Flow	Chloridazon 0.43	3.0	200 l/ha	3/4/02	Pre-em	None
CONV	Mandolin Flo Goltix WG oil	Phenmedipham 0.16 Metamitron 0.7+ oil	1.2 1.0kg 0.5	100 l/ha	10/5/02	2 lvs	
CONV	Betanal Flo Venzar Flow oil	Phenmedipham 0.16 Lenacil 0.44+ oil	2.5 0.4 0.5	100 l/ha	6/6/02	6-8 lvs	POLAV CHEAL FALCO
LL	Liberty	Glufosinate 0.2	3.0	100 l/ha	6/6/02	6-8 lvs	POLAV FALCO CHEAL
RR	Roundup Biactive	Glyphosate 0.36	2.0	100 l/ha	6/6/02	6-8 lvs	POLAV CHEAL FALCO

ROTATION 3

Table 10.1.11. NIAB in Rotation 3, Year 1 (1998-1999): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure /volume	Applic-ation date	Crop growth stage at herbicide application*	Main weed sp. growth stage at herbicide application*
CONV	Butisan S	Metazachlor 0.5	2.5	3bar/240l /ha	15.10.98	GS: 1.2-1.3	POAAN,/TRIAE : 11-15, URTUR: 2-6leaf, CAPBP/CHEAL 4-6 leaf
CONV	Fusilade EW	Fluazifop-P-butyl 0.2	0.75	3bar/240l /ha	15.10.98	GS: 1.2-1.3	
LL	Liberty	Glufosinate 0.2	3	3bar/240l /ha	16.10.98	GS: 1.2-1.3	POAAN,/TRIAE : 11-15, URTUR: 2-6 leaf, CAPBP/CHEAL 4-6 leaf
RR	Roundup Biactive	Glyphosate 0.36	3	3bar/240l /ha	23.11.98	GS: 1.7-1.11	POAAN,/TRIAE : 20-25, URTUR: 6-8 leaf, CAPBP/CHEAL 6-8 leaf
IMI	Imazamox	Imazamox 0.07	1.75	3bar/240l /ha	11.11.98	GS 1.5-1.9	POAAN,/TRIAE : 20-25, URTUR: 6-8 leaf, CAPBP/CHEAL 6-8 leaf

*growth stage at herbicide application or pre herbicide weed assessment timing

Table 10.1.12. Broom's Barn Rotation 3, Year 1 (1999-2000):Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Application date	Crop GS at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Benazalox +	Benazolin+ clopyralid 0.3+ 0.05	2.3kg	2.5 bar/ 200 l/ha	2.02.99	GS 1.5	AVESA GS: 25, STEME 15 cm, VERPE
	Laser	Cycloxydim 0.2	0.6				10 cm
LL	Liberty	Glufosinate 0.2	4	2.5 bar/ 200 l/ha	2.02.99	GS 1.5	AVESA GS: 25, STEME 15 cm, VERPE 10 cm
RR	Roundup Biactive	Glyphosate 0.36	2	2.5 bar/ 200 l/ha	2.02.99	GS 1.5	AVESA GS: 25, STEME 15 cm, VERPE 10 cm
IMI*	Benazalox +	Benazolin+ clopyralid 0.3+ 0.05	2.3kg	2.5 bar/ 200 l/ha	2.02.99	GS 1.5	AVESA GS: 25, STEME 15 cm, VERPE
	Laser	Cycloxydim 0.2	0.6				10 cm

*no imazamox applied at Brooms Barn plots treated with conventional herbicide

Table 10.1.13. Morley Research Centre Rotation 3, Year 1 (1999-2000): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ Volume	Applic- ation. date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CON	Butisan S	Metazachlor 0.5	1.5	200 l/ha 4 bar	12/9/98	Pre-em	None
IMI*	Butisan S + Benazalox	Metazachlor 0.5 Benazolin 0.3 + clopyralid 0.05	1.5 + 0.75kg	200 l/ha 4 bar	11/11/98	GS 13-14	POAAN LAMPU MATSS
LL	Liberty	Glufosinate 0.2	3.0	200 l/ha 4 bar	11/11/98	GS 13-14	POAAN LAMPU MATSS
RR	Roundup Biactive	Glyphosate 0.36	2.0	200 l/ha 4 bar	11/11/98	GS 13-14	POAAN LAMPU MATSS

*no imazamox applied at Morley Research Centre plots treated with conventional herbicide

Table 10.1.14 . NIAB in Rotation 3, Year 3 (2001): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ Volume	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Goltix WG	Metamitron 70%w/w	1.5kg	3bar/120l /ha	8.05.01	1st application: cotyledon,	All cotyledon
CONV	Nortron Flo	Ethofumesate 0.5	0.7	3bar/120l /ha	8.05.01		
CONV	Debut	Triflusulfuron-methyl 50%w/w	30g	3bar/120l /ha	25.05.01	2nd application: 2-4 leaf	VIOAR cot-4leaf, VERPE 2 leaf POLAV 2 leaf, CAPBP 6 leaf,
CONV	Betanal Compact	Desmedipham+ Phenmedipham 0.05+0.193	1.5	3bar/120l /ha	25.05.01		
CONV	Debut	Triflusulfuron-methyl 50%w/w	30g	3bar/120l /ha	7.06.01	3rd application: 6-8 leaf CONV*	BRANA 4-6 leaf, VERHE 2-6 branches, VERPE 2-4 leaf, VIOAR 6-8 leaf.
CONV	Betanal Compact	Desmedipham+ Phenmedipham 0.05+0.193	1.5	3bar/120l /ha	7.06.01		
CONV*	Luxan	Chloridazon 0.43		3bar/120l /ha	17.04.01	Pre-em	
LL	Liberty	Glufosinate 0.2	3	3bar/120l /ha	21.05.01	1st application: 2-4leaf,	URTUR 2leaf, VERHE cotyledon-2leaf, BRANA cotyledon-2leaf
LL	Liberty	Glufosinate 0.2	3	3bar/120l /ha	5.06.01	2nd application: 6-8 leaf	URTUR 4leaf, VERHE 2leaf, BRANA 4 leaf.
RR	Roundup Biactive	Glyphosate 0.36	3	3bar/120l /ha	31.05.01	4-6 leaf	BRANA up to 8 leaf, POAAN GS 26.

Note: CONV* plots received the same post emergence treatments as conventional plots.
LL plots containing LL tolerant oilseed rape volunteers received a tank mix of Goltix Flow (metamitron 0.7kg a.i/l) 1.7kg/ha 21.05.01.
RR plots containing RR tolerant oilseed rape volunteers received a tank mix of Goltix Flow (metamitron 0.7kg a.i/l) 1.7kg/ha 21.05.01.
Note: P1,P2 etc = product 1 and 2 etc

Table 10.1.15. Broom's Barn Rotation 3, Year 3 (2001): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Applic-ation date	Crop GS at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Mandolin + Venzar	Phenmedipham 0.2 + Lenacil 0.2	2.5 + 0.4	2 bar/ 100 l/ ha	23.05.01	Cot - 2 TL	Cotyledon to 2 leaf CHEAL, VERPE, STEME, VIOAR, CAPBP
CONV	Betanal Progress +	Desmedipham+ Ethofumesate+ Phenmedipham 0.03+0.15+0.08	0.75+	2 bar/ 100 l/ ha	12.06.01	4-6 TL	CHEAL, STEME, VERPE
	Debut +	+ Triflusulfuron-methyl 0.5 +	30g+				
	Venzar	Lenacil 0.2	0.4				
LL	Liberty [+ Goltix]*	Glufosinate 0.2 [+ Metamitron 0.7]	4 [+ 1.7]	2 bar/ 200 l/ ha	13.06.01	4-6 TL	CHEAL, STEME, VERPE
RR	Roundup Biactive [+ Goltix]*	Glyphosate 0.36 [+ Metamitron 0.7]	3 [+ 1.7]	2 bar/ 200 l /ha	13.06.01	4-6 TL	CHEAL, STEME, VERPE

Note: year 1 plots designated as IMI were treated with conventional herbicides
* Treatment on LL and RR plots which followed LL or RR oilseed rape resp. included Goltix

Table 10.1.16. Morley Research Centre Rotation 3, Year 3 (2001): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate /ha	Pressure /volume	Applic-ation. date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Pyramin DF	Chloridazon 0.65	1.7kg	150 l/ha	4/5/01	Pre-em	None
CONV	Betanal Flo + Venzar Flow	Phenmedipham 0.16 + Lenacil 0.44	1.2 l/ha 0.2 l/ha	100 l/ha	30/5/01	2 lvs	FALCO BRANA LAMPU
CONV	Betanal Flo + Venzar Flo + Toil	Phenmedipham 0.16+ lenacil + oil	1.5 l/ha 0.4 l/ha 1.0 l/ha	100 l/ha	22/6/01	6-8 lvs	FALCO BRANA LAMPU
CONV	Betanal Progress OF + Venzar	Pmp 0.076 + Dmp 0.025 + etho 0.151** Lenacil 0.44	1.5 l/ha 0.4 l/ha	100 l/ha	9/7/01	60% cover	BRANA FALCO
RR	Roundup Biactive	Glyphosate 0.36	2.0 l/ha	200 l/ha	12/6/01	4-6 lvs	FALCO CHEAL BRANA VIOAR LAMPU
LL	Liberty	Glufosinate 0.2	2.0 l/ha	200 l/ha	12/6/01	4-6 lvs	As Above
LL	Liberty	Glufosinate 0.2	2.0 l/ha	200 l/ha	16/7/01	60-70% cover	As above
RR on RR	Roundup Biactive + Goltix WG + Oil	Glyphosate 0.36+ Metamitron 0.7 + oil	2.0 l/ha 1.7 kg 1.0 l/ha	200 l/ha	12/6/01	4-6 lvs	As above
RR on plots with RR rape vols	Roundup Biactive + Debut	Glyphosate 0.36 + Triflusulfuron 0.5	2.0 l/ha 30 g/ha	200 l/ha	16/7/01	60-70% cover	As above
LL on plots with LL rape vols	Liberty + Goltix WG + oil	Glufosinate 0.2+ Metamitron 0.7+ oil	2.0 l/ha 1.7kg 1.0 l/ha	200 l/ha	12/6/01	4-6 lvs	As above
LL on plots with LL rape vols	Liberty + Debut	Glufosinate 0.2+ Triflusulfuron 0.5	2.0 l/ha 30 g/ha	200 l/ha	16/7/01	60-70% cover	As above

** pmp+dmp+etho = phenmedipham + desmedipham + ethofumesate

ROTATION 4

Table 10.1.17. NIAB in Rotation 4, Year 2 (1999-2000): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ Volume	Applic-ation date	Crop growth stage at herbicide application*	Main weed sp. growth stage at herbicide application*
CONV	Butisan S	Metazachlor 0.5	2.5	3bar/240l /ha	4.10.99	GS: 1.2-1.3	CONV: CAPBP, VERPE 2-4leaf, TRIAE GS 22.
CONV	Fusilade EW	Fluazifop-P-butyl 0.2	0.75	3bar/240l /ha	4.10.99		
LL	Liberty	Glufosinate 0.2	3	3bar/240l /ha	11.11.99		LL, RR, IMI: CAPBP 4-8leaf, VERPE2-4leaf, URTUR up to 10leaf, TRIAE GS 24.
RR	Roundup Biactive	Glyphosate 0.36	3	3bar/240l /ha	11.11.99		
IMI	Imazamox	Imazamox 0.07	1.75	3bar/240l /ha	11.11.99		

*growth stage at herbicide application or pre herbicide weed assessment timing
Note: P1,P2= product 1 and 2

Table 10.1.18. Rothamsted Research in Rotation 4, Year 2 (1999-2000): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure /volume	Application date	Crop growth stage at herbicide application*	Main weed sp. growth stage at herbicide application*
CONV	Katamaran	Metazachlor + quinmerac 0.375+0.125	2	2bar/220 l/ha	11.09.99	Pre-em	Pre-em
CONV	Alpha Trifluralin 48EC	Trifluralin 0.48	2	2bar/220 l/ha	11.09.99	Pre-em	Pre-em
LL	Liberty	Glufosinate 0.2	3	2bar/220 l/ha	29.10.99	GS 1.5	TRIAE GS 12, VIOAR cot-1leaf.
RR	Roundup Biactive	Glyphosate 0.36	3	2bar/220 l/ha	28.10.99	GS 1.5	TRIAE GS 21, VIOAR 2-5leaf, STEME 6leaf VERPE 1-3leaf
IMI	Imazamox	Imazamox 0.07	1.75	2bar/220 l/ha	27.10.99	GS 1.5	TRIAE GS 21, VIOAR 2-5leaf, STEME 6leaf VERPE 1-3leaf

*growth stage at herbicide application or weed assessment timing

Table 10.1.19. Scottish Agricultural College Aberdeen in Rotation 4, Year 2 (1999-2000): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume/ nozzles	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Katamaran	Metazachlor + quinmerac 0.375+0.125	2.0	100 l/ha	5.09.99		
CONV*	Kerb	Propyzamide 50% w/v	1.4kg	100 l/ha	26.11.99	GS 1.4 - 1.6	STEME 2 leaf to 20 cm, POAAN GS 12-23, VIOAR cotyledon to 6 leaf, MATsp. cotyledon to 6 leaf, MYOAR cotyledon to 6 leaf, FUMOF cotyledon to 8 leaf, HORVU GS 21-23
LL	Liberty	Glufosinate 0.2	3	100 l/ha	26.11.99	"	"
RR	Roundup Biactive	Glyphosate 0.36	3	100 l/ha	26.11.99	"	"

ROTATION 5

Table 10.1.20. Broom's Barn Rotation 5 Year 3 (2001): Herbicide treatment programme for HT crops.

Treatment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pressure/ volume	Application date	Crop GS at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Twin + Goltix	Ethofumesate: Phenmedipham 94:97 + Metamitron 0.7	2+ 1	2 bar/ 100 l/ ha	23.05.01	Cot - 2 TL	Cotyledon CHEAL, VERPE, FALCO
CONV	Twin + Goltix	Ethofumesate: Phenmedipham 94:97 + Metamitron 0.7	3+ 1	2 bar/ 100 l /ha	12.06.01	4-6 TL	FALCO, TRIRE, LAMPU, POLAV
LL	Liberty	Glufosinate 0.6	4	2 bar/ 200 l/ ha	13.06.01	4-6 TL	FALCO, TRIRE, LAMPU, POLAV
RR	Roundup Biactive	Glyphosate 0.36	3	2 bar/ 200 l /ha	13.06.01	4-6 TL	FALCO, TRIRE, LAMPU, POLAV

Table 10.1.21. Morley Research Centre Rotation 5 Year 3 (2001): Herbicide treatment programme for HT crops.

Treat-ment	Product name	Active ingredient (kg a.i./l or %w/w)	Dose rate (l/ha or kg/ha)	Pres/ volume	Applic-ation. date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
CONV	Pyramin DF	Chloridazon 0.65	1.7 kg	150 l/ha	4/5/01	Pre-em	None
CONV	Betanal Flo + Goltix WG	Phenmedipham 0.16 Metamitron 0.7	1.2 1.0kg	100 l/ha	30/5/01	2 lvs	FALCO VIOAR
CONV	Betanal Flo Goltix WG Oil	Phenmedipham 0.16 Metamitron 0.7 Oil	1.5 1.0kg 1.0	100 l/ha	22/6/01	6-8 lvs	FALCO POAAN VIOAR VERPE MATSS Weed beet
CONV	Betanal Progress OF Venzar Flow Laser Actipron	Pmp 0.076+dmp 0.025 +etho 0.151** Lenacil 0.44 Cycloxydim 0.2 Oil	1.5 0.4 1.25 1.0	100 l/ha	9/7/01	60% cover	As above + AVEFA
RR	Roundup Biactive	Glyphosate 0.36	2.0	200 l/ha	12/6/01	4-6 lvs	FALCO POAAN VIOAR VERPE MATSS Weed beet
RR	Roundup Biactive	Glyphosate 0.36	2.0	200 l/ha	9/7/01	60% cover	Weed beet
LL	Liberty	Glufosinate 0.2	2.0	200 l/ha	12/6/01	4-6 lvs	FALCO POAAN VIOAR VERPE MATSS Weed beet
LL	Liberty	Glufosinate 0.2	2.0	200 l/ha	11/7/01	60-70% cover	Weed beet

** pmp+dmp+etho = phenmedipham + desmedipham + ethofumesate

10.2 APPENDIX 2. HERBICIDE TREATMENTS APPLIED TO CEREAL CROPS GROWN IN ROTATIONS AT EACH CENTRE.

ROTATION 1A AND 1B (and Rotation 4 at SAC).

Table 10.2.1 Rothamsted Research : Herbicide treatments applied to wheat in Rotation 1a and 1b, Year 2 and 3 - treatments applied to all plots

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 2	PDQ	Diquat and paraquat 0.08:0.12	3	6.9.99	Pre-sowing	Pre-sowing
Year 2	Duplosan	Mecoprop-P 0.6	0.5	3.11.99	GS1.1-1.4	VIOAR, PAPRH, STEME cots-3leaf
Year 2	Tolkan Turbo	Difluenican + isoproturon 0.02:0.5	2	3.11.99	GS1.1-1.4	"
Year 2	Hawk	Clodinafop-propargyl + trifluralin 0.012:0.383	2.5	14.12.00	-	-
Year 3	Sting Eco	Glyphosate 0.12	2	28.09.00	Pre-sowing	Pre-sowing
Year 3	Avadex Excel 15G	Tri-allate 15% w/w				
Year 3	Stomp 400 SC	Pendimethalin 0.4	2	14.12.00	GS 13	VIOAR, PAPRH, STEME cotyledon -4-6leaf
Year 3	Lexus 50 DF	Flupyrsulfuron-methyl 50%w/w	20g	14.12.00	GS 13	
Year 3	Starane 3	Fluroxypyr 0.2	0.5	11.05.01	-	-
Year 3	Ally	Metsulfuron-methyl 20%w/w	20g	11.05.01	-	-
Year 3	Grasp	Tralkoxydim 0.25	7.5	23.05.01	-	-
Year 3	Azural	Glyphosate 0.36	4	30.07.01	-	-

Table 10.2.2. Scottish Agricultural College : Herbicide treatments applied to cereals grown in Rotation 1a and 1b Year 2 and 3 and Rotation 4 years 1, 3 and 4: treatments applied to all plots

Rotation and Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
R1. Year 2	No herbicide applied					No or very few weeds present
R1. Year 3	Reglone	Diquat 0.2	2/l/ha	17 .08.01	Crop > 30% moisture	
R4. Year 1	No herbicide applied					No or very few weeds present
R4. Year 3	No herbicide applied					No or very few weeds present
R4. Year 4	Ally + Tolkan	Metsulfuron-methyl 20%w/w + isoproturon 0.50	15g/ha + 1l/ha	16.04.02		No or very few weeds present

Table 10.2.3. NIAB: Herbicide treatments applied to wheat in Rotation 1a Year 2 and 3 - treatments applied to all plots

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 2	Stomp 400 SC	Pendimethalin 0.4	3	13.11.99	GS 13	BRANA, GALAP, CIRsp, ANGAR, VICFA cotyledon
Year 2	IPU	Isoproturon 0.5	3	13.11.99	-	-
Year 2	Mecoprop-P	Mecoprop-P 0.6	2	13.03.00	-	-
Year 3	Lexus Class	Carfentrazone-ethyl+flupyrsulfuron	0.02kg	5.03.01	-	-
Year 3	Stomp 400 SC	Pendimethalin 0.4	3	5.03.01	-	-
Year 3	Starane 2	Fluroxypyr 0.2	0.75	23.05.01	-	-
Year 3	Luxan MCPA	MCPA 0.5	1	23.05.01	-	-

ROTATION 2.

Table 10.2.4. Broom's Barn: Herbicide treatments applied to cereal crops in Rotation 2, Year 2 and 3 - treatments applied to all plots

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 2	IPU	Isoproturon 0.5	2	14.10.99		
Year 2	Stomp 400 SC	Pendimethalin 0.4	2	14.10.99		
Year 2	Grasp	Tralkoxydim 0.25	1.4	5.05.00		
Year 3	IPU	Isoproturon 0.5	2	20.02.01		
Year 3	Stomp 400 SC	Pendimethalin 0.4	2	20.02.01		

ROTATION 3

Table 10.2.5 NIAB : Herbicide treatments applied to wheat at in Rotation 3, Years 2 and 4 - treatments applied to all plots.

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 2 P1	Stomp 400 SC	Pendimethalin 0.4	3	13.11.99	GS 13	POAAN, VERHE, VIOAR, URTUR cotyledon-2leaf
Year 2 P2	IPU	Isoproturon 0.5	3	13.11.99		
Year 2 P3	Duplosan	Mecoprop-P 0.6	2	13.03.00	-	-
Year 2 P4	Starane 2	Fluroxypyr 0.2	0.75	13.03.00	-	-
Year 4 P1	Stomp 400 SC	Pendimethalin 0.4	3	13.11.02	GS 12	BRANA, CAPBP, VIOAR, POAAN, SONsp, URTUR, VERPE
Year 4 P2	IPU	Isoproturon 0.5	3	13.11.02		
Year 4 P3	Ally	Metsulfuron-methyl 20%	15g	11.04.02	-	-

Note: P1,P2 etc.= product 1, 2 etc

Table 10.2.6. Broom' s Barn: Herbicide treatments applied to cereal crops in Rotation 3, Year 2 and 4 - treatments applied to all plots.

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 2 P1	Stomp 400 SC	Pendimethalin 0.4	2	14.10.99		
Year 2 P2	IPU	Isoproturon 0.5	2	14.10.99		
Year 2 P3	Grasp	Tralkoxydim 0.25	1.4	05.05.00		
Year 4 P1	Stomp 400 SC	Pendimethalin 0.4	3	13.11.02		
Year 4 P2	IPU	Isoproturon 0.5	3	13.11.02		

Note: P1,P2 etc.= product 1, 2 etc

Table 10.2.7. Morley Research Centre: Herbicide treatments applied to cereals grown in Rotation 3 Year 2 and 4 - treatments applied to all plots.

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 2 P1	Avadex XL 15G	Tri allate 15% w/w	0.015kg	17.10.99		
Year 2 P2	Angle	Cyanazine+ terbuthylazine 0.306:0.261	1	26.10.99		
Year 2 P3	Panther	Diflufenican +isoproturon 0.05:0.5	0.2	26.10.99		
Year 2 P4	Ally	Metsulfuron-methyl 20%w/w	0.02kg	6.05.00		
Year 2 P5	Duplosan	Mecoprop-P 0.6	1	6.05.00		
Year 4 P1	Standon DFF-IPU	Diflufenican+ isoproturon 0.05:0.5	0.5	15.11.01		
Year 4 P2	Arelon 500	Isoproturon 0.5	2.5	15.11.01		
Year 4 P3	Topik + oil	Clodinafop-propargyl 0.24	0.11	9.05.02		
Year 4 P4	Starane	Fluroxypyr 0.2	0.75	2.05.02		
Year 4 P5	Ally	Metsulfuron-methyl 20%w/w	0.02kg	2.05.02		

Note: P1,P2 etc.= product 1, 2 etc

ROTATION 4.

Table 10.2.8 Rothamsted Research : Herbicide treatments applied to wheat in Rotation 4, Year 1, 3 and 4 - treatments applied to all plots

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Appli-cation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 1 P1	Isoguard	Isoproturon 0.5	2	3.12.98	GS 20	SENVU, VIOAR, STEME, VERPE
Year 1 P2	Stomp 400 SC	Pendimethalin 0.4	2	3.12.98		
Year1 P3	Ally	Metsulfuron-methyl 20%w/w	20g	30.04.99	-	-
Year 1 P4	Duplosan	Mecoprop-P 0.6	0.5	30.04.99	-	-
Year 1 P5	Grasp	Tralkoxydim 0.25	1.0	14.05.99	-	-
Year 3 P1	Avadex Excel 15G	Tri-allate 15% w/w	2	13.10.00	GS 11-14	VIOAR, STEME, GALAP, APHAR
Year 3 P2	Stomp 400 SC	Pendimethalin 0.4	2	13.10.00	-	-
Year 3 P3	Lexus 50 DF	Flupyrsulfuron-methyl 50%w/w	20g	14.12.00	-	-
Year 3 P4	Starane 2	Fluroxypyr 0.2	0.5	11.05.01	-	-
Year 3 P5	Ally	Metsulfuron-methyl 20%w/w	20g	11.05.01	-	-
Year 3 P6	Starane 2	Fluroxypyr 0.2	0.5	11.05.01	-	-
Year 4 P1	Stomp 400 SC	Pendimethalin 0.4	2	12.10.01	-	-
Year 4 P2	Lexus 50 DF	Flupyrsulfuron-methyl 50%w/w	20g	12.10.01	-	-
Year 4 P3	Ally	Metsulfuron-methyl 20%w/w	20g	16.04.02	-	-
Year 4 P4	Duplosan	Mecoprop-P 0.6	0.5	16.04.02	-	-
Year 4 P5	Topik	Clodinafop-propargyl 0.24	0.1	17.05.02	-	-

Note: P1,P2 etc.= product 1, 2 etc

Table 10.2.9. NIAB : Herbicide treatments applied to wheat in Rotation 4, Year 1, 3 and 4 - treatments applied to all plots

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Application date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 1 P1	IPU	Isoproturon 0.5	3	3.12.98	-	-
Year 1 P2	Stomp 400 SC	Pendimethalin 0.4	3	3.12.98	-	-
Year 3 P1	IPU	Isoproturon 0.5	3	3.04.01	GS 13-14	GALAP, BRANA VERsp 1-2 leaf
Year 3 P2	Stomp 400 SC	Pendimethalin 0.4	3	3.04.01		
Year3 P3	Duplosan	Mecoprop-P 0.6	0.5	23.05.01	-	-
Year 3 P4	Starane 2	Fluroxypyr 0.2	0.5	23.05.01	-	-
Year 4 P1	IPU	Isoproturon 0.5	3	14.02.02	GS 13-14	GLAP, BRANA VERsp 1-2 leaf
Year 4 P2	Stomp 400 SC	Pendimethalin 0.4	3	14.02.02		
Year 4 P3	Duplosan	Mecoprop-P 0.6	0.5	4.04.02	-	-

Note: P1,P2 etc.= product 1, 2 etc

ROTATION 5.

Table 10.2.11 Broom's Barn : Herbicide treatments applied to cereals in Rotation 5, Years 1, 2 and 4 - treatments applied to all plots

Year	Product name	Active ingredient (kg a.i/l or %w/w)	Dose rate (l/ha or kg/ha)	Applic-ation date	Crop growth stage at herbicide application	Main weed sp. growth stage at herbicide application
Year 1 P1	Swipe	Bromoxynil + ioxynil + mecoprop-P	4.4	15.03.99		
Year 1 P2	Grasp	Tralkoxydim 0.25	1.0	30.03.99		
Year 1 P3	IPU	Isoproturon 0.5	2	30.03.99		
Year 2 P1	IPU	Isoproturon 0.5	2	10.12.99		
Year 2 P2	Stomp 400 SC	Pendimethalin 0.4	2	10.12.99		
Year 4 P1	IPU	Isoproturon 0.5	2	19.10.01		
Year 4 P2	Stomp 400 SC	Pendimethalin 0.4	2	19.10.01		

Note: P1,P2 etc.= product 1, 2 etc

10.3 . APPENDIX 3. Site specific information, experimental plans and layouts, and untreated data.

The BRIGHT experiments were located at 5 sites and crops grown as shown in Table 10.3.1.

Table 10.3.1. Cropping in the four year rotations at the five participating sites

Year	Rotation 1a/1b[2]	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Sites	NIAB/Roth/SAC	BB/MOR	BB/MOR/NIAB	NIAB/Roth/SAC	BB/MOR
1	Winter oilseed rape	Sugar beet	Winter oilseed rape	Winter cereal[1]	Winter cereal[1]
2	Winter cereal	Winter cereal	Winter cereal	Winter oilseed rape	Winter cereal
3	Winter cereal	Winter cereal	Sugar beet	Winter cereal	Sugar beet
4	Winter oilseed rape	Sugar beet	Cereal / fallow	Cereal / fallow	Cereal / fallow

BB= Brooms Barn, MOR=Morley Research Centre, Roth=Rothamsted Research, NIAB=NIAB, SAC=Scottish Agricultural College, Aberdeen,

[1]The two rotations designated as undersown in year 1 received rape (R.4) or beet (R.5) seeds during late summer which were ploughed under to simulate seeds shed from a previous crop establishing a seedbank of potential volunteers.

[2]NIAB - Rotation 1a only, Rothamsted Research and SAC Aberdeen Rotation 1a and 1b

Plans of the experiments at each site are described in the site details below.

10.3.1 Site specific information, experimental plans and layouts.

The BRIGHT experiments were located at 5 sites and details of the sites, their previous cropping and the experimental plans are as follows:

a). NIAB HQ trial grounds at Cambridge: two fields were used.

Rotation 1. was in Field 26 on a slightly stony clay, with seasonal waterlogging in some areas, field that had been in an arable crop rotations of wheat, peas and beans.

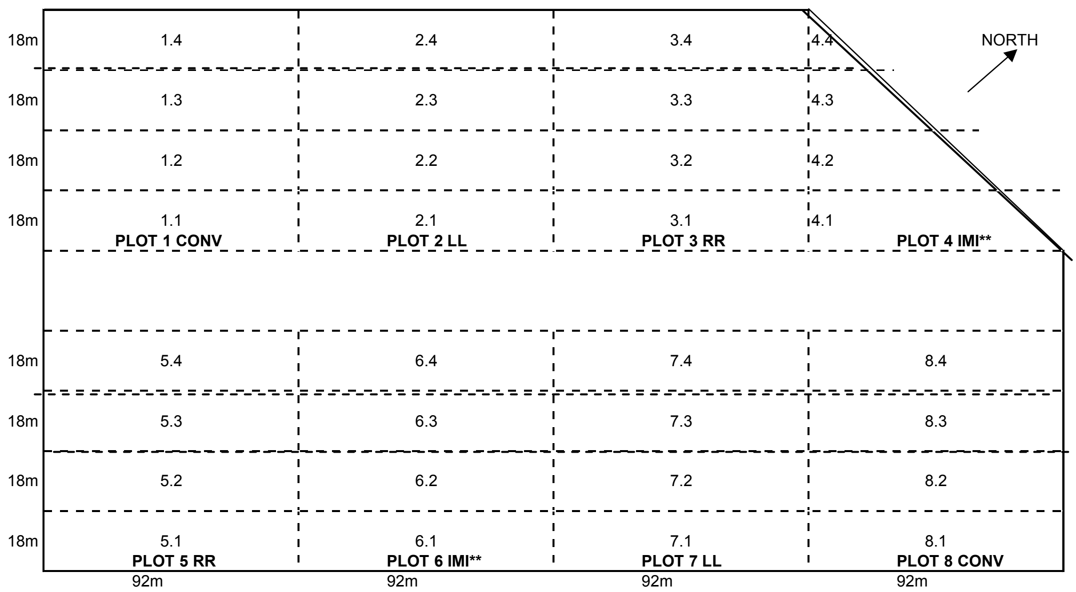
Previous cropping:

YEAR	CROP
1994	winter wheat / 7.8ha
1994	winter beans / 0.7ha
1994	combinable peas / 1.5ha
1995	winter wheat / 9.6ha
1995	winter beans / 0.4ha
1996	winter wheat / 10ha
1997	winter beans / 10ha
1998	winter wheat / 10ha

NIAB ROTATION 1

YEAR 1 WINTER OILSEED RAPE

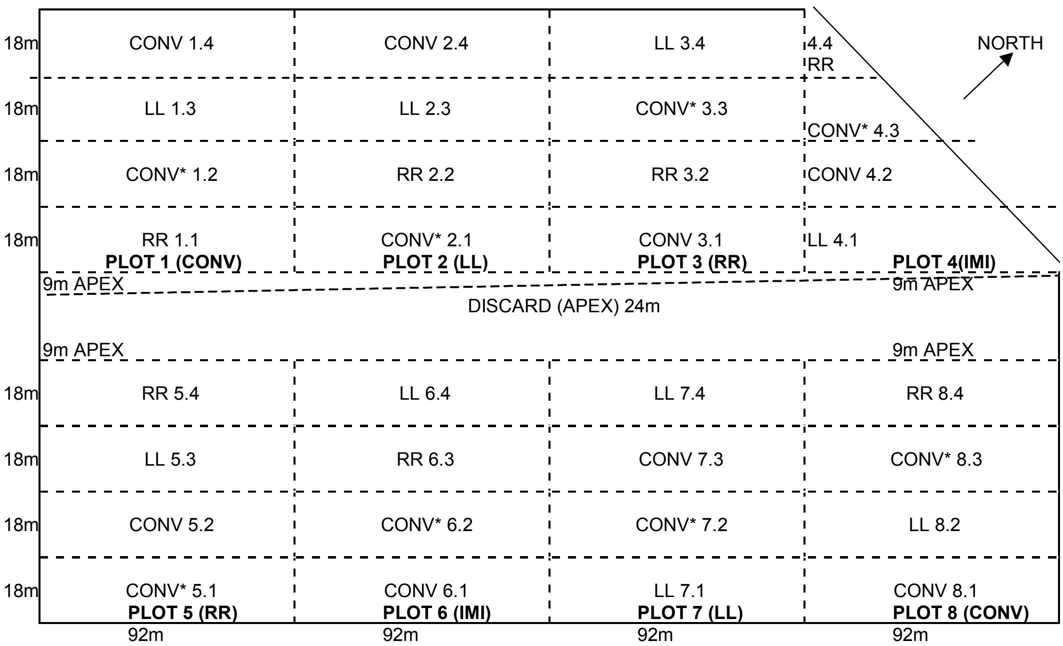
LOCATION OF PLOTS, SUB-PLOTS AND WINTER RAPE VARIETIES



**IMI plots only received 24m wide area of Imazamox on the left hand side of the plot

NIAB Rotation 1
YEAR 4 - WINTER OILSEED

LOCATION OF PLOTS, SUB-PLOTS AND WINTER RAPE



Treatments: CON = conventional crop, LL = glufosinate resistant crop, RR = glyphosate resistant crop, IMI = imidazolinone resistant crop (yr 1), CON* = alternative conventional (Yr4)

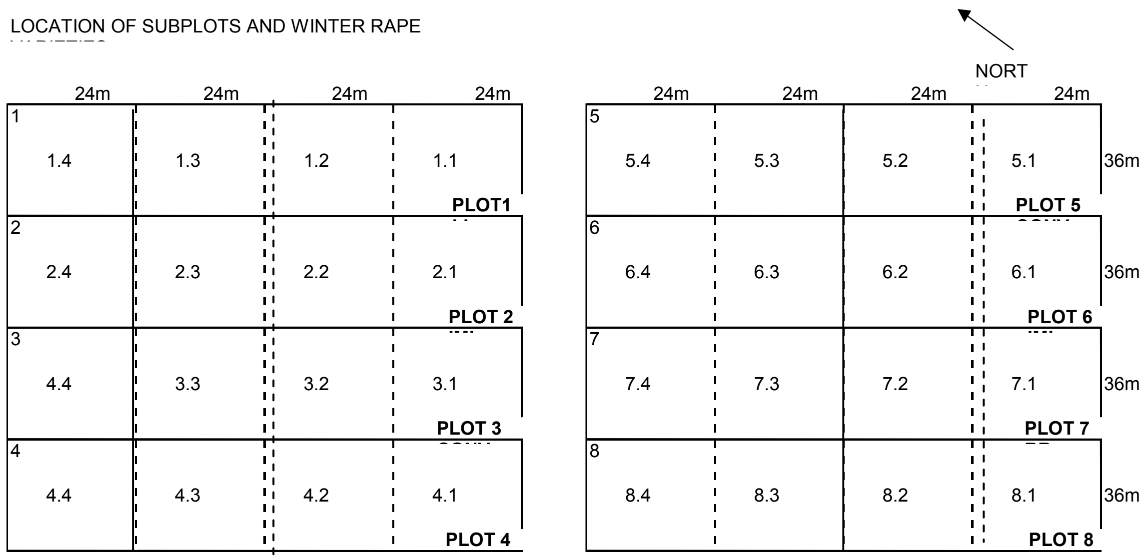
Rotations 3 and 4 were located in field 8 & 9 with a well drained stony clay loam soil which had been in a range of experimental cropping including some areas that had been in grass pathways for several years.

Previous cropping:

1994	Cereal/winter rape/brassicas
1995	winter rape (approx1ha)
1996	winter wheat (whole field)
1997	Linseed trials (whole field)
1998	winter wheat (whole field)

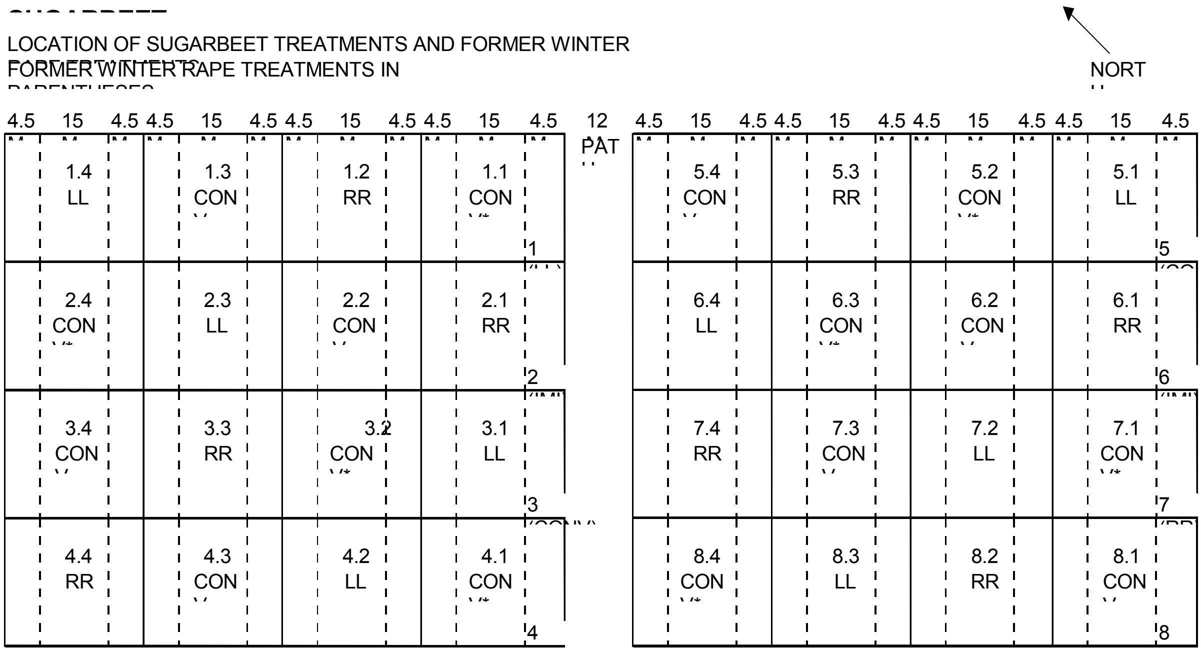
NIAB ROTATION 3
YEAR 1 WINTER OILSEED RAPE

LOCATION OF SUBPLOTS AND WINTER RAPE

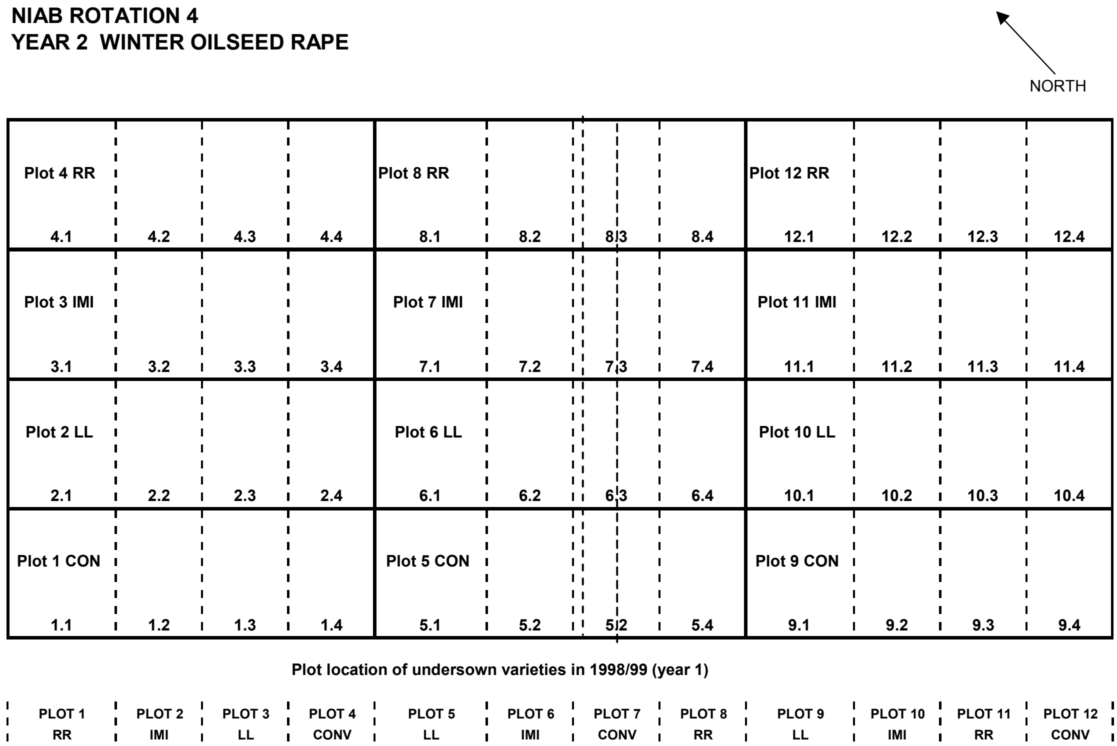


NIAB Rot 3
YEAR 3

LOCATION OF SUGARBEET TREATMENTS AND FORMER WINTER
FORMER WINTER RAPE TREATMENTS IN



Treatments: CON = conventional crop, LL = glufosinate resistant crop, RR = glyphosate resistant crop, IMI = imidazolinone resistant crop (yr 1), CON* = alternative conventional (Yr3)



Treatments: CON = conventional crop, LL = glufosinate resistant crop, RR = glyphosate resistant crop, IMI = imidazolinone resistant crop (yr 1)

b). Rothamsted Research Blackhorse field at Redbourn, Herts, : Rotations 1, and 4 were located in the same field. Soil type: topsoil : flinty silty clay loam (18-27% clay)

subsoil : mottled clay-with-flints within 80cm depth

Date of last oilseed rape crop: 1992

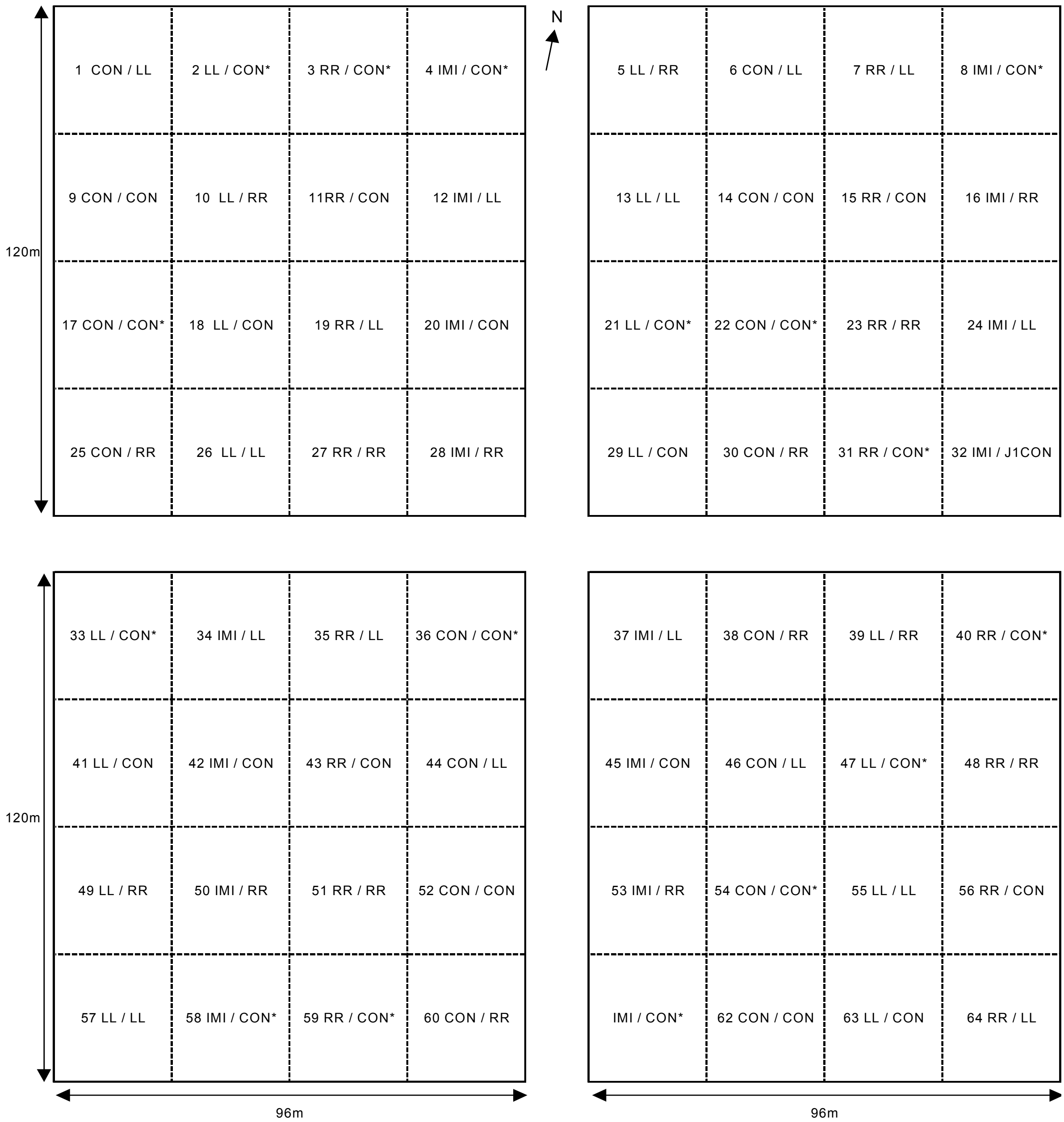
Previous cropping:

YEAR	**CROP**
1994	Winter Oats
1995	Winter Wheat
1996	Winter. Oats
1997	Winter Wheat
1998	Winter Oats

Rotation 1 Rothamsted

Years 1 & 4 Winter oilseed rape

First letters are Year 1 treatment second letters Year 4 treatments
Location of plots.



N.B. only IMI plots 4 and 10 were sprayed with imazamox.

Plots 18 x30m in year 4

Treatments: CON = conventional, CON* = alternative conventional used in Year 4

IMI = imidazolinone resistant rape

LL = glufosinate resistant rape

RR = glyphosate resistant rape

Rotation 4 Rothamsted

Owing to the failure of rape seed undersown in year 1 there were 4 sub-plots of each treatment per replicate.

Year 2 Winter oilseed rape

1 LL	2 LL	3 LL	4 LL	5 CON	6 CON	7 CON	8 CON	9 IMI	10 IMI	11 IMI	12 IMI
13 CON	14 CON	15 CON	16 CON	17 RR	18 RR	19 RR	20 RR	21 LL	22 LL	23 LL	24 LL
25 IMI	26 IMI	27 IMI	28 IMI	29 IMI	30 IMI	31 IMI	32 IMI	33 RR	34 RR	35 RR	36 RR
37 RR	38 RR	39 RR	40 RR	41 LL	42 LL	43 LL	44 LL	45 CON	46 CON	47 CON	48 CON

48cm

48cm 48cm 48cm

Plots 12 x 12m in year 2

Treatments: CON = conventional
IMI = imidazolinone resistant rape
LL = glufosinate tolerant rape
RR = glyphosate tolerant rape

c). Broom's Barn Research Station, Higham, Suffolk: **Rotations 2, 3 and 5** were located in adjacent fields which had never grown oilseed rape, as described below.

Rotation 2

Soil type: Coarse sandy loam over sand
Previous cropping:

YEAR	**CROP**
1994	Winter barley
1995	Winter barley
1996	Sugar beet
1997	Spring barley
1998	Winter oats

Rotation 3

Soil type: Grey sandy clay to sand loam
Previous cropping:

1994	Winter barley
1995	Winter barley
1996	Sugar beet
1997	Spring barley
1998	Winter oats

Rotation 5

Soil type: Grey sandy clay to sand loam
Previous cropping:

1994	Three years experiment on fat hen population dynamics. Plots under rotation with some of spring barley, winter barley and sugar beet in each year
1995	""
1996	""
1997	Set-aside
1998	FWAG light land mix

Broom's Barn Rotation 3

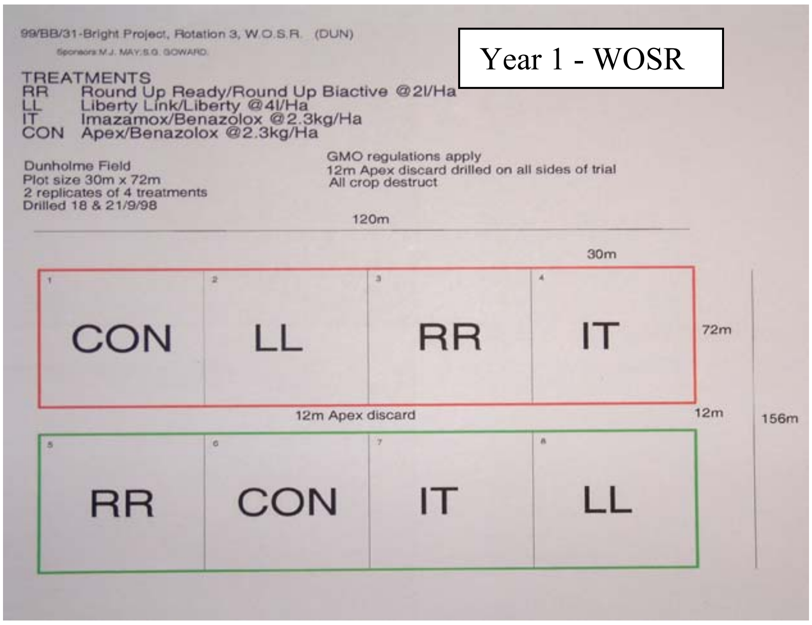
Treatments:

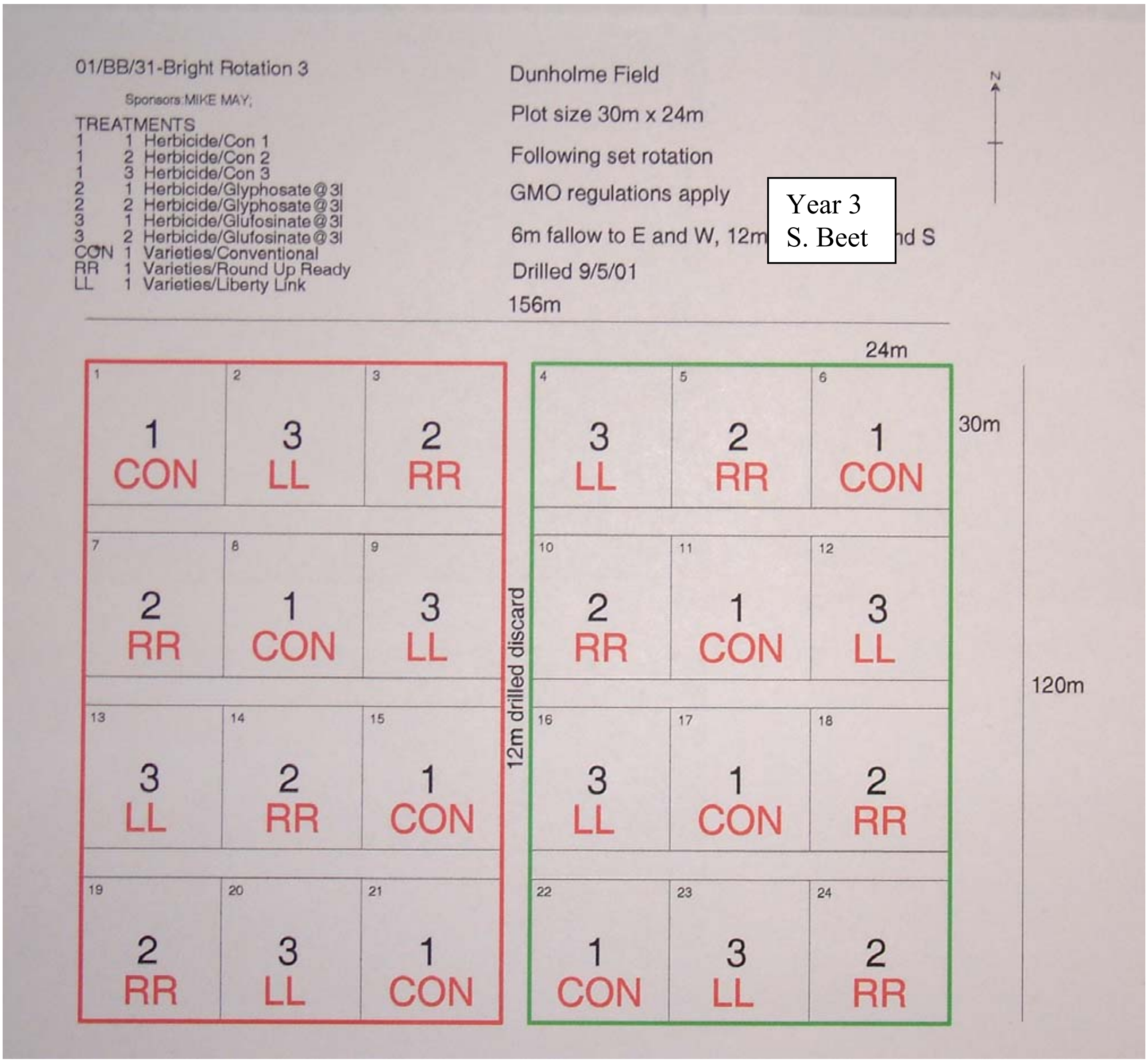
CON = conventional crop

LL = glufosinate resistant crop

RR = glyphosate resistant crop

IT = imidazolinone resistant crop





Year 1 Sugar Beet

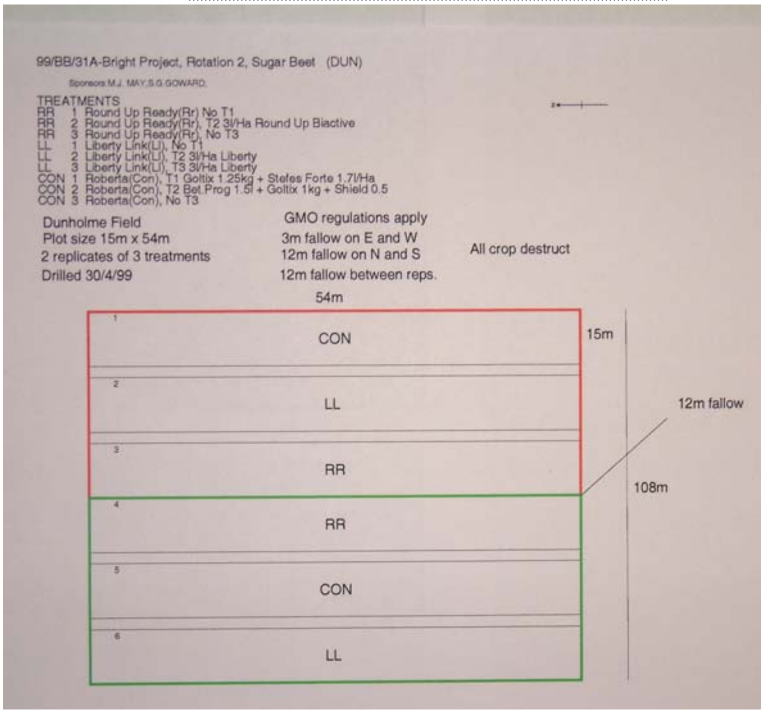
Broom's Barn Rotation 2

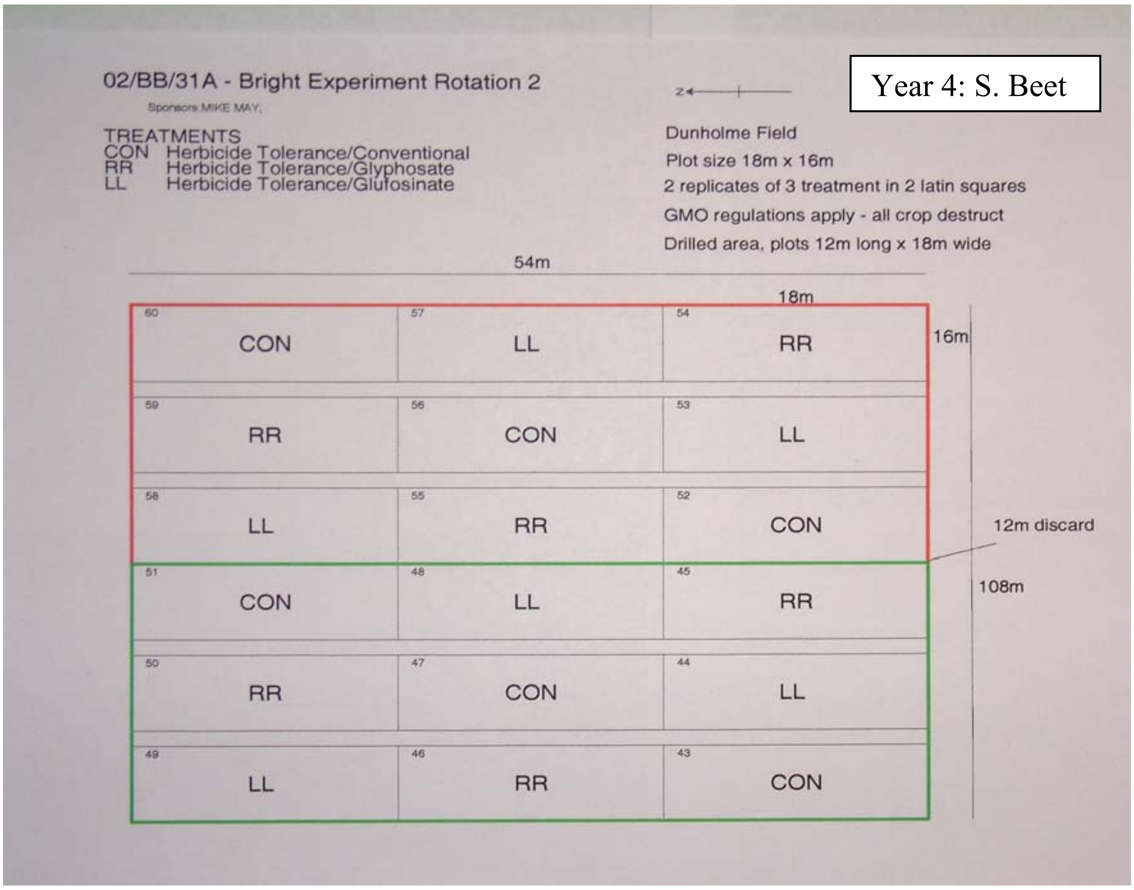
Treatments:

CON = conventional

LL = glufosinate resistant crop

RR = glyphosate resistant crop

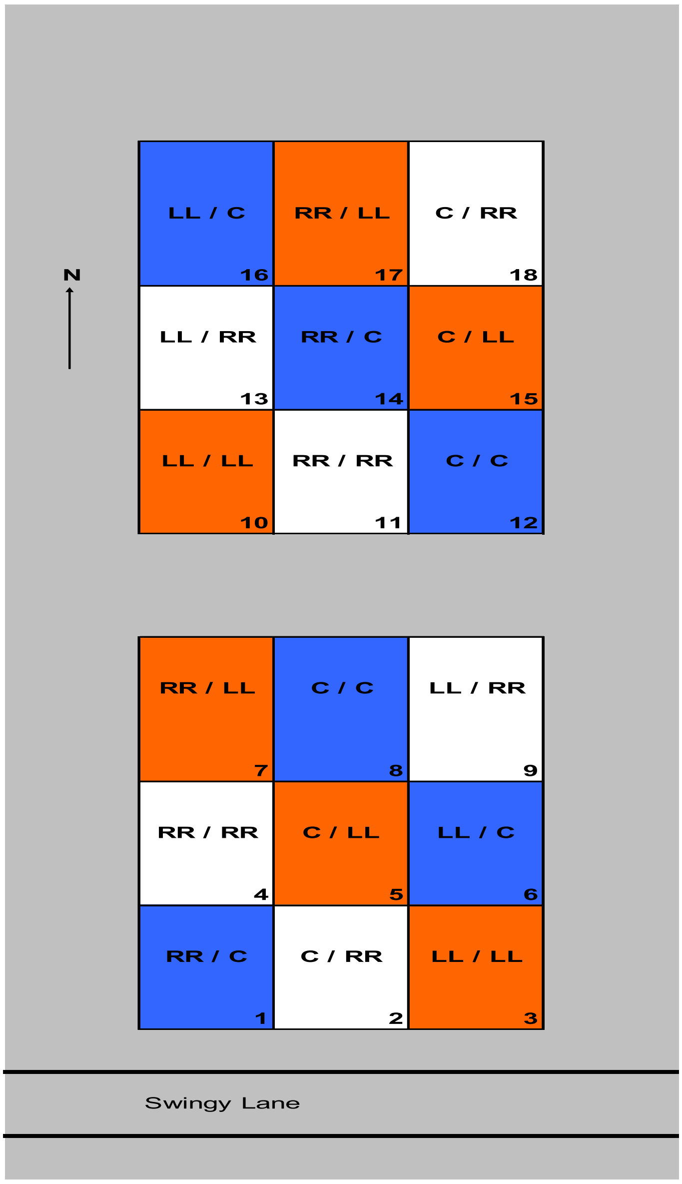




d). **Morley Research Centre, Morley, Norfolk**: **Rotations 2, and 5** were located in 2 parts of Hobarts field and **Rotation 3** was located in Bayle field both with sandy clay loam soils which had never grown oilseed rape and had grown the following rotations:

Rotation 2 : **Hobarts field**

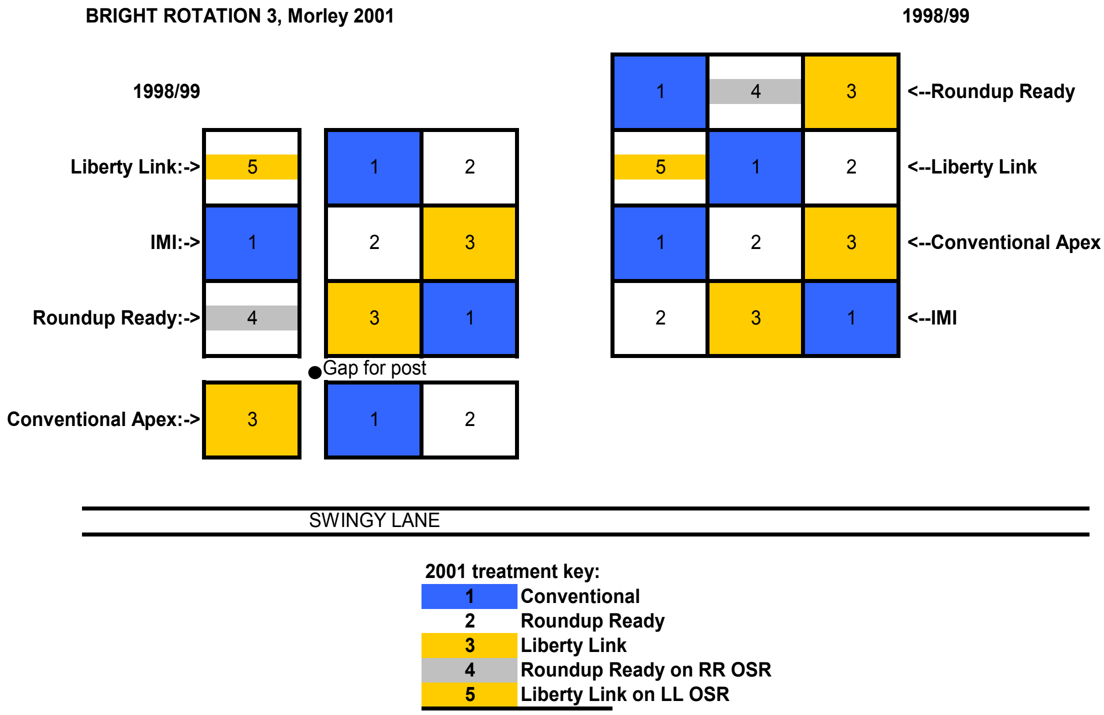
Soil Type:	Sandy Clay loam
Previous crops	
1994	Winter barley
1995	Winter beans
1996	Sugar beet
1997	Spring barley
1998	Winter barley



First letters show treatments in Year 1 and second, treatments in Year 4
Plot sizes are 24 x 24m in Year 4

Treatments: CON = conventional
LL = glufosinate tolerant rape
RR = glyphosate tolerant rape

Morley Rotation 3



Rotation 3: Bayle field

Soil Type:	Sandy Clay loam
Last rape:	Never
Previous crops	
1994	Winter beans
1995	Winter wheat
1996	Sugar beet
1997	Winter wheat
1998	Linseed

Rotation 5 : Hobarts field

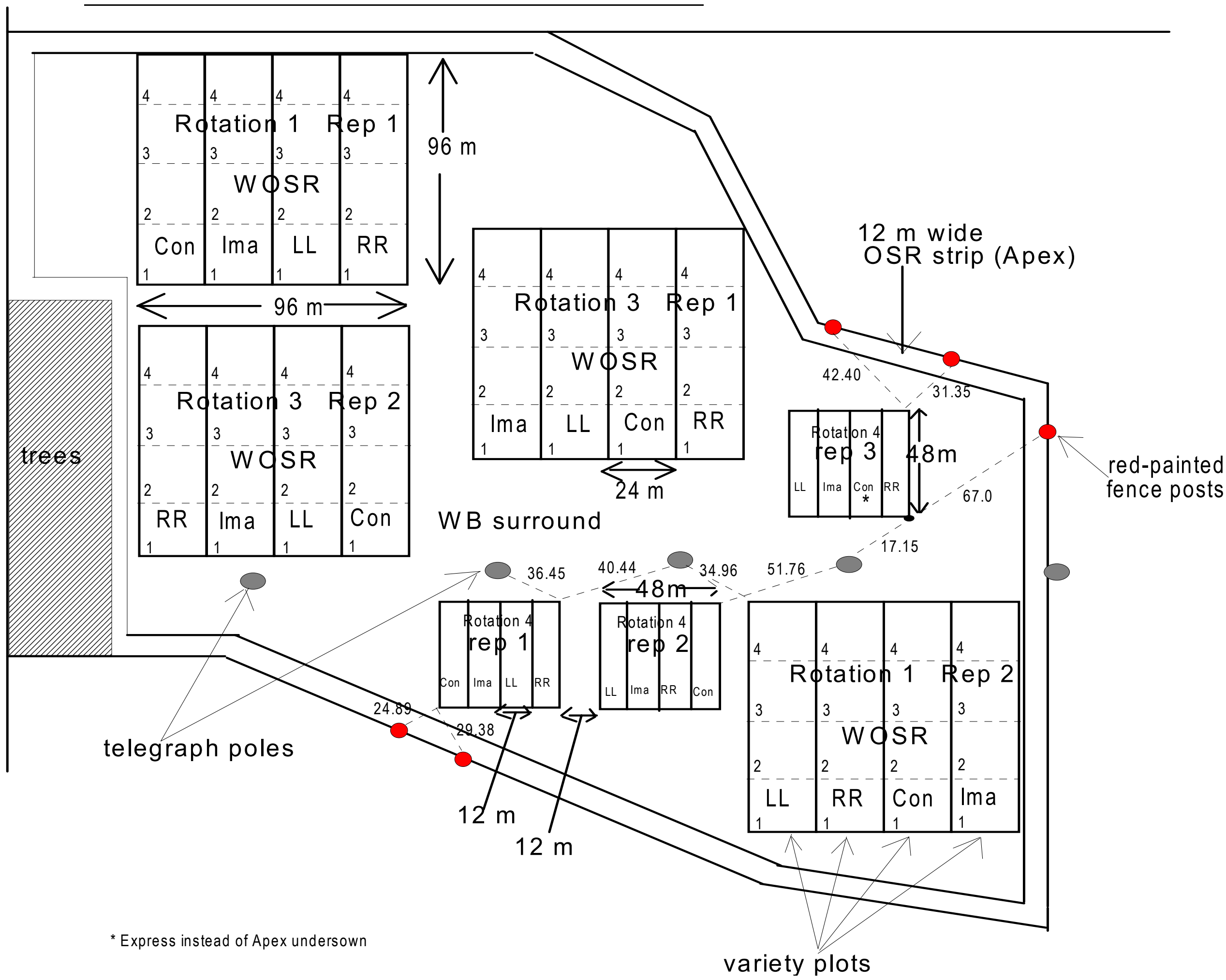
Soil Type:	Sandy Clay loam
Previous crops	
1994	Winter barley
1995	Winter beans
1996	Sugar beet
1997	Spring barley
1998	Winter barley

e). Scottish Agricultural College, Aberdeen. :

The site for **rotations 1,3 and 4** was located at SAC Tillycorthie Farm, Udny, Aberdeenshire, UK.
Soil Type: In the heavy land category, classified as land use capability class 3(2), imperfectly drained Tarves Association soil, sandy clay loam.
The field had included field experiments in 1996 to 1998

Previous 5 years cropping:

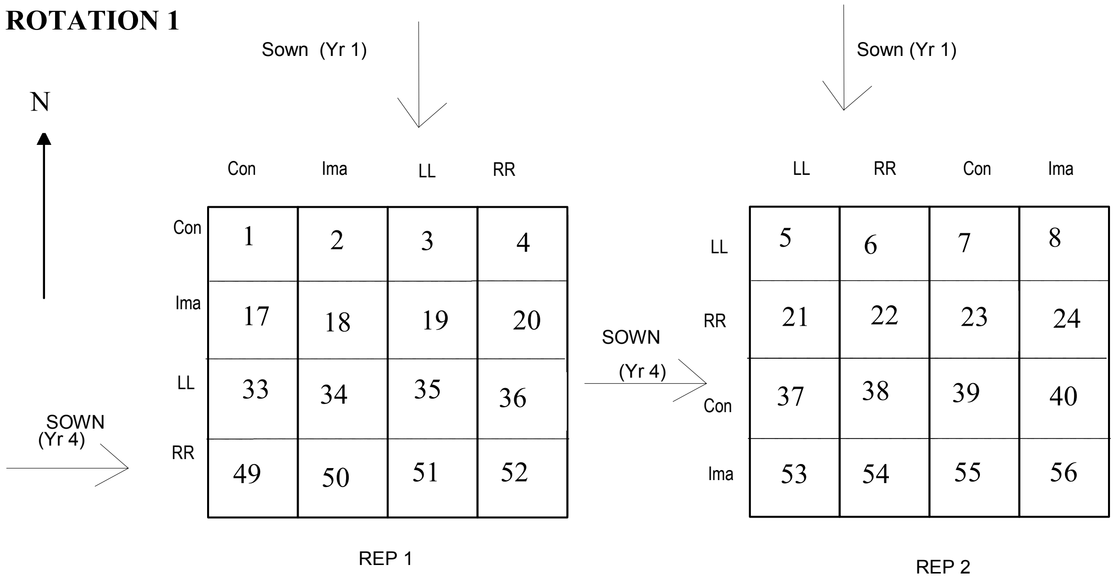
Year	Crop
1993/94	Set-aside
1994/95	Winter oilseed rape
1995/96	Winter barley
1996/97	Winter barley
1997/98	Winter barley
1998/99	BRIGHT OSR trial + WB



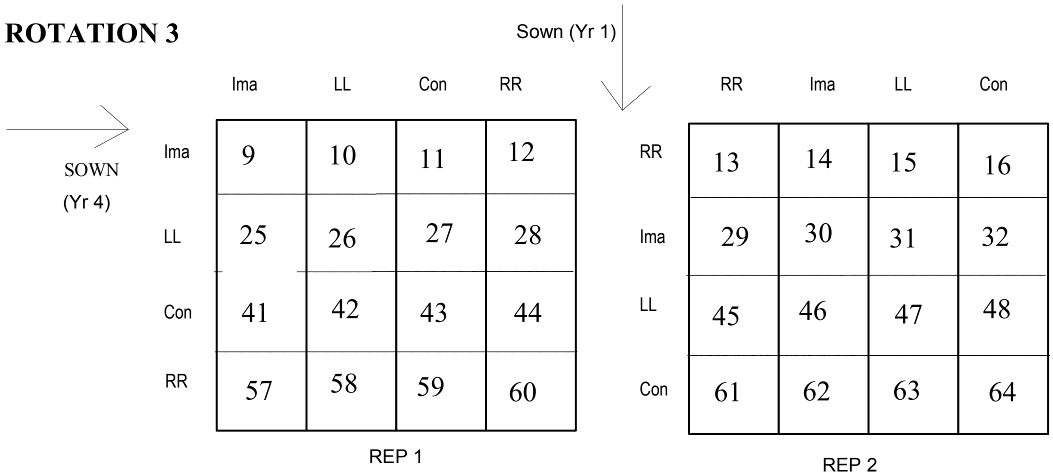
* Express instead of Apex undersown

SAC Plan of four replicates of combined rotations 1 and 3

ROTATION 1

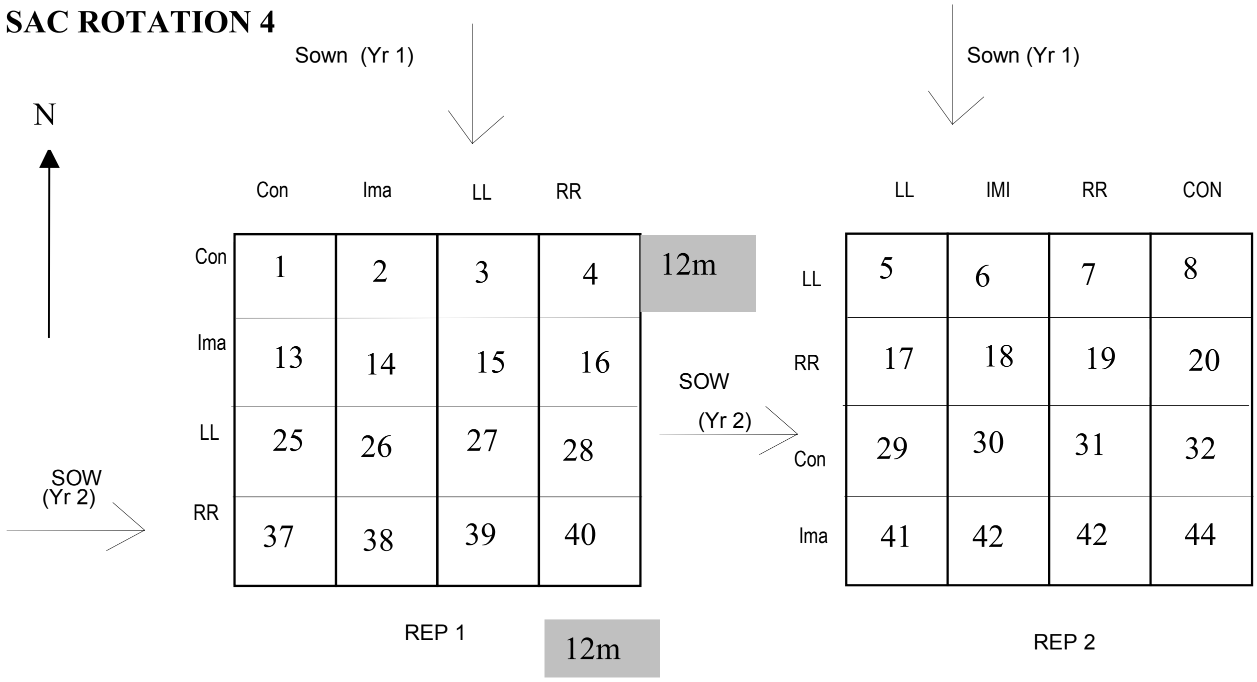


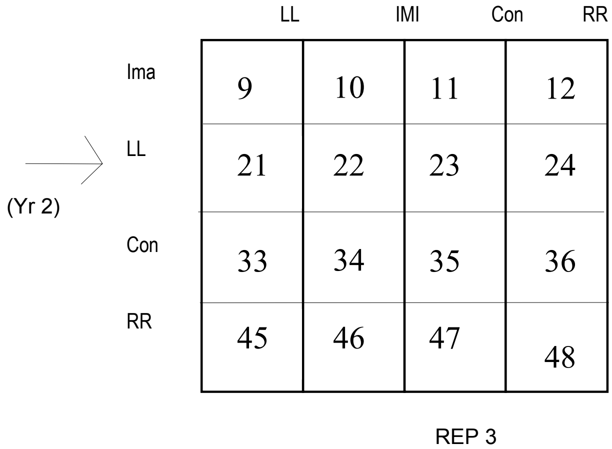
ROTATION 3



Treatments: Con = conventional crop, LL = glufosinate resistant crop, RR = glyphosate resistant crop, Ima = imidazolinone resistant crop (yr 1), CON* = alternative conventional (Yr3)

SAC ROTATION 4





First year plots sown north to south, 48 m long and 12 m wide, and then whole area oversown with Barley. In second year the plots were drilled crossways west to east, 48 m long and 12 m wide to give 48 sub-plots of 12m x 12m.

Treatments: Con = conventional crop, LL = glufosinate resistant crop, RR = glyphosate resistant crop, Ima = imidazolinone resistant crop (yr 1),

10.3.2 Plot sizes

The plot sizes used at each site and in each experiment varied according to size of fields, field equipment operating widths and the subsequent splitting into plots for the different treatments in later years. They are shown in the above plans and the plot sizes at each site, in each year of each rotation grown are summarised in Table 1.3.2.

Table 10.3.2 Plot sizes (m) used in each year of each rotation at each experimental site.

		Rotation				
Site	**Year**	**1**	**2**	**3**	**4**	**5**
Rothamsted	1	24 x 120			12 x 48	
	2	24 x 120			12 x 12	
	3	24 x 120			12 x 12	
	4	18 x 30			12 x 12	
SAC	1	24 x 96			12 x 48	
	2	24 x 96			12 x 12	
	3	24 x 96			12 x 12	
	4	24 x 24			12 x 12	
NIAB	1	72 x 92 #		96 x 36	24 x 96	
	2	72 x 92 #		96 x 36	24 x 24	
	3	72 x 92 #		24 x 36	24 x 24	
	4	18 x 92 #		24 x 36	24 x 24	
Broom's	1		16 x 54	30 x 72		108 x 54
	2		16 x 54	30 x 72		108 x 54
Barn	3		16 x 54	30 x 24*		18 x 18*
	4		16 x 18*	30 x 24		18 x 18
Morley	1		24 x 96	24 x 96		100 x 50
	2		24 x 96	24 x 96		100 x 50
	3		24 x 96	24 x 24*		16 x 24*
	4		24 x 24*	24 x 24		16 x 24

* when beet was grown although the whole plot received herbicides only the central strip 12m wide (the whole length of the plot) was sown with beet

\# One IMI plot was 72 x 24m in years 1-3 and then was divided into 18 x 24m plots in year 4.

(Grey shading) No experiments

10.3.3 Meteorological Data

Weather records were taken at the 5 BRIGHT experimental sites for the periods 1998 -2002. These are available from Jeremy Sweet (jeremysweet303@aol.com) or from Peter Lutman (peter.lutman@bbsrc.ac.uk).

10.3.4 Assessments made at each site

The following tables list the dates and weed assessment methods (quadrat sizes) at each site and in each rotation over the four year period of the BRIGHT experiments.

Table 10.3.3 . Rotation 1a/1b annual assessment timings, quadrat numbers and size at NIAB*, Rothamsted Research and Scottish Agricultural College Aberdeen****

Site/Year	Pre-herbicide (autumn)	Post-herbicide (spring)	Biomass (summer)
NIAB Year 1	20 x 0.25m^2 quadrats per sub-plot 26.10.98-28.10.98	12 x 0.25m^2 quadrats per sub-plot 09.03.99	4 x 1m^2 quadrats per sub-plot 24.06.99
NIAB Year 2	20 x 0.25m^2 quadrats per sub-plot 29.10.99	20 x 0.25m^2 quadrats per sub-plot 01.03.00	4 x 0.25m^2 quadrats per sub-plot 24.06.00
NIAB Year 3	20 x 0.25m^2 quadrats per sub-plot 06.03.01	20 x 0.25m^2 quadrats per sub-plot 30.04.01	4 x 0.25m^2 quadrats per sub-plot 26.06.01
NIAB Year 4	20 x 0.25m^2 quadrats per sub-plot 25.09.01-26.09.01	20 x 0.25m^2 quadrats per sub-plot 19.03.02	4 x 1m^2 quadrats per sub-plot 17.06.02
Rothamsted Reseach Year 1	20 x 1m^2 quadrats per sub-plot .Conv 28.09.98-01.10.98. IMI 09 -12.10.98. 12 x 0.5m^2 LL and RR 12-13.11.98	12 x 1m^2 quadrats per subplot 02-09.03.99	4 x 1m^2 quadrats per sub-plot 09-11.06.99, 17-18.06.99
Rothamsted Resaerch Year 2	12 x 0.5m^2 quadrats per sub-plot 18-21.10.99	12 x 0.5m^2 quadrats per sub-plot 21-22.03.00	4 x 1m^2 quadrats per sub-plot 27-28.06.00
Rothamsted Research Year 3	12 x 0.5m^2 quadrats per sub-plot or 0.2m^2 at high weed density 20-22.11.00	12 x 0.5m^2 quadrats per sub-plot 26-27.03.01	4 x 1m^2 quadrats per sub-plot 25-28.06.01
Rothamsted Reseach Year 4	12 x 0.5, 0.25, 0.1m^2 per subplot depending on density 28.09.01(conv) 16-19.10.01 (RR LL CON*)	12 x 0.5m^2 quadrats per sub-plot 6-08.03.02	4 x 1m^2 quadrats per sub-plot 10-14.06.02
SAC Aberdeen Year 1	20 x 1m^2, 0.25m^2, 0.1m^2 depending on weed density	No quadrats counted, weeds assessed by % cover	8 x 0.5m^2 quadrats per sub-plot 23-25.06.99
SAC Aberdeen Year 2	No assessment made[1]	30 quadrats per sub-plot 0.25 m^2 or 0.1m^2 depending on density 10.05.00-27.07.00	8 x 0.5m^2 quadrats per sub-plot 12-17.07.00
SAC Aberdeen Year 3	No assessment made[1]	20 quadrats per sub-plot 0.25 m^2 or 0.1m^2 depending on density 24.05.01-26.06.01	8 x 0.5m^2 quadrats per sub-plot - only for Rot 1 Rep 1 Conv. All the rest had 4 x 0.5 m^2 quadrats. 24.07.01-7.08.01
SAC Aberdeen Year 4	12 x quadrats per sub-plot 0.25 m^2 or 0.1m^2 depending on density 25.10.01-23.11.01	12 x quadrats per sub-plot 0.25 m^2 or 0.1m^2 depending on density 20.03.02-22.03.02	8 x 0.5m^2 quadrats per sub-plot + 2 x 0.5 m^2 quadrats on untreated area 04.07.02-19.07.02

[1]No herbicide applied to plots, weed density/m^2 extremely low

*NIAB Rotation 1a **Rothamsted Research and SAC Aberdeen Rotation1a and Rotation1b

Table 10.3.4. Rotation 2 annual assessment timings, quadrat numbers and size at Broom's Barn and Morley Research Centre

Site/Year	Pre-herbicide (autumn/spring)	Post-herbicide (spring/summer)	Biomass (summer)
BB Year 1	20 x 1 m^2 quadrats per sub-plot 24.05.99 20 x 0.25m^2 quadrats per sub-plot 08.06.99 20 x 1m^2 quadrats per sub-plot 06.07.99	15 x 0.25 m^2 quadrats per subplot 16.08.99	4 x 1m^2 quadrats per sub-plot 26.08.99
BB Year 2	12 x 0.25 m^2 quadrats per subplot 12.10.99	12 x 1 m^2 quadrats per subplot 20.04.00	4 x 1m^2 quadrats per sub-plot 06.07.00
BB Year 3	12 x 1 m^2 quadrats per subplot 28.11.00	12 x 1 m^2 quadrats per subplot 27.04.01	4 x 1m^2 quadrats per sub-plot 27.07.01
BB Year 4	12 quadrats per subplot, 1m^2 or 0.5 m^2 depending on density 17.05.02	12 x 1 m^2 quadrats per subplot 23.07.02	4 x 1m^2 quadrats per sub-plot 27.08.02
MOR Year 1	No record as pre-em herbicide used	"	12. 03..99 10x 0.3m^2 Quadrats per sub-plot weed count and biomass
MOR Year 2	"	16.05.00 4 x 0.3m^2 Quadrats per sub-plot	No records
MOR Year 3	"	04.05.01 6 x 0.5 m^2 Quadrats per sub-plot	"
MOR Year 4	"	29.05.02 and 17.07.02 10x 0.3m^2 Quadrats per sub-plot	28.08.02 10x 0.3m^2 Quadrats per sub-plot

*Pre-em treatment on conv

Table 10. 3. 5. Rotation 3 annual assessment timings, quadrat numbers and size at Broom's Barn, Morley Research Centre and NIAB

Site/Year	Pre-herbicide (autumn)	Post-herbicide (spring)	Biomass (summer)
NIAB Year 1	20 x 0.25m^2 quadrats per sub-plot 26.10.98-28.10.98	12 x 0.25m^2 quadrats per sub-plot 09.03.99	4 x 1m^2 quadrats per sub-plot 24.06.99
NIAB Year 2	20 x 0.25m^2 quadrats per sub-plot 11.11.99	20 x 0.25m^2 quadrats per sub-plot 09.03.00	4 x 0.25m^2 quadrats per sub-plot 05.07.00
NIAB Year 3	20 x 0.5m^2 per sub-plot 08.05.01 (Conv/conv*) 14.05.01 (LL and RR)	20 x 0.5m^2 quadrats per sub-plot 04-05.07.01	2 x 1m^2 quadrats per sub-plot 11.09.01
NIAB Year 4	12 x 0.25m^2 quadrats per sub-plot 02.11.01	20 x 0.25m^2 quadrats per sub-plot 02.04.02	2 x 1m^2 quadrats per sub-plot 24.06.02
MOR Year 1	11.11.98 20 x 0.3m^2 Quadrats per sub-plot	12. 03.99 10x x 0.3m^2 Quadrats per sub-plot	21.10.99 10x x 0.3m^2 Quadrats per sub-plot
MOR Year 2	08.05.00 4 x 0.3m^2 Quadrats per sub-plot	08.05.00 4 x 0.3m^2 Quadrats per sub-plot	26.07.00 4 x 1.0m^2 Quadrats per sub-plot
MOR Year 3	Pre-em herbicides used	05.07.01 & 02.08.01 10x x 0.3m^2 Quadrats per sub-plot	07/08/01 10x x 0.3m^2 Quadrats per sub-plot
MOR Year 4	No weeds	No weeds	24/07/02 10x x 0.3m^2 Quadrats per sub-plot
BB Year 1	12 x 1m^2 quadrats per sub-plot 03.02.99	12 x 1m^2 quadrats per sub-plot 16.03.99	4 x 1m^2 quadrats per sub-plot 14.07.99
BB Year 2	12 x 0.25m^2 quadrats per sub-plot 11.10.99	12 x 1m^2 quadrats per sub-plot 18.04.00	4 x 1m^2 quadrats per sub-plot 06.07.00
BB Year 3	12 x 0.5m^2 quadrats per sub-plot 25.05.01 12 x 0.5m^2 quadrats per sub-plot 14.06.01,	12 x 0.5m^2 quadrats per sub-plot 07.08.01	4 x 1m^2 quadrats per sub-plot 06.09.01
BB Year 4	12 x 1m^2 quadrats per sub-plot 29.10.01	12 x 1m^2 quadrats per sub-plot 04-05.04.02	4 x 1m^2 quadrats per sub-plot 18.07.02

Table 10.3.6. Rotation 4 annual assessment timings*, quadrat numbers and size at NIAB, Rothamsted Research and SAC Aberdeen

Site/Year	Pre-herbicide (autumn)	Post-herbicide (spring)	Biomass (summer)
NIAB Year 2	20 x 0.25m^2 quadrats per sub-plot 05.10.99 for (CONV) 14.10.99 (RR,LL IMI)	12 x 0.25m^2 quadrats per sub-plot 13.03.00	4 x 1m^2 quadrats per sub-plot 20.06.00
NIAB Year 3	20 x 0.25m^2 quadrats per sub-plot 04.04.01	20 x 0.25m^2 quadrats per sub-plot 29.05.01	4 x 1m^2 quadrats per sub-plot 27.06.01
NIAB Year 4	15 x 0.25m^2 quadrats per sub-plot 26-27.11.01	15 x 0.25m^2 quadrats per sub-plot 03.04.02	2 x 1m^2 quadrats per sub-plot 24.06.02
Rothamsted Research Year 1	No assessment	12 or 8 x 0.5m^2 quadrats per sub-plot 08-14.01.99	No assessment
Rothamsted Research Year 2	10 x 0.5m^2 or 0.2 m^2 quadrats per sub-plot 05-06.10.99 (CONV), 27.10.99 (IMI), 04.11.99 (LL), 08.11.99 (RR)	10 x 0.5 m^2 quadrats per sub-plot 01-03.03.00	2 x 1m^2 quadrats per sub-plot 12-13.06.00
Rothamsted Research Year 3	10 x 0.5m^2 or 0.2 m^2 quadrats per sub-plot 23-24.11.01	10 x 0.5m^2 quadrats per sub-plot 29.03.01	2 x 1m^2 quadrats per sub-plot 02-03.07.01
Rothamsted Research Year 4	10 x 0.5m^2 quadrats per sub-plot 29-31.10.01	10 x 0.5m^2 quadrats per sub-plot 25.03.02	2 x 1m^2 quadrats per sub-plot 16.07.02
SAC Aberdeen Year 2	10 quadrats per subplot, 0.25 m^2 or 0.1 m^2 depending on density 29.10.99-10.11.99	10 quadrats per subplot, 0.25 m^2 or 0.1 m^2 depending on density 17.04.00-18.4.00	8 x 0.5 m^2 quadrats per subplot 21.07.00
SAC Aberdeen Year 3	None	20 quadrats per subplot, 0.25 m^2 or 0.1 m^2 depending on density 05.06.01-26.06.01	none
SAC Aberdeen Year 4	None	10 quadrats per subplot, 0.25 m^2 or 0.1 m^2 depending on density 19.03.02 - 20.03.02	4 x 0.5 m^2 quadrats per subplot 24.07.02

*No formal assessments were made in year 1 apart from Rothamsted Research where a post herbicide count was made in January 1999

Table 10.3.7 . Rotation 5 annual assessment timings, quadrat numbers and size at Broom's Barn and Morley Research Centre

Site/Year	Pre-herbicide (autumn)	Post-herbicide (spring)	Biomass (summer)
BB Year 3	12 quadrats per subplot, 1m^2 or 0.5 m^2 depending on density 24.05.01 12 x 0.5m^2 quadrats per sub-plot 14.06.01,	12 x 0.5m^2 quadrats per sub-plot 08.08.01	4 x 0.25m^2 quadrats per sub-plot 07.09.01
BB Year 4	12 x 0.125m^2 quadrats per sub-plot 19.10.01	12 x 1m^2 quadrats per sub-plot 05-12.04.02	4 x 1m^2 quadrats per sub-plot 18.07.02
MOR Year 1.	No weeds	22.09.99- 10 x 0.3m^2 Quadrats per sub-plot	No weeds
MOR year 2.	No weeds	16.05.00 10 x 0.3m^2 Quadrats per sub-plot	No weeds-
MOR Year 3	Not assessed	05.07.01 4 x 0.3m^2 quadrats per sub-plot and weed beet in whole plot area (12x14m).	02.08.01 weed beet in whole plot area (12x14m).
MOR Year 4	Not assessed	10.04.02 10 x 0.3m^2 Quadrats per sub-plot	No weeds

10.3.5 Untreated data

In some experiments at some sites (depending on lay out, space and other factors), untreated plots were grown adjacent to treated plots and sown with different cultivars in order to assess background levels of germinating and surviving weeds in the absence of any treatment for their control. Generally these plots developed large dense weed populations which smothered the crop reducing its vigour and growth.
Examples of the data collected are presented below.
No data from these untreated plots was analysed.

Table 10.3.8 Rothamsted Rotation 1 year 4: Weeds present in untreated plots sown with the different HT and conventional cultivars.

	Autumn	**Spring**	**Biomass**
	Total number of weeds present		
Cultivar	(no/m^2)	(no/m^2)	(g/m^2)
CONV#	71.6	122.7	36.1
CON*	186.7	141.9	71.7
LL	165.8	141.0	59.2
RR	158.2	140.3	58.8
	Number of weed **species** present		
	(no/m^2)	(no/m^2)	(g/m^2)
CONV	14	16	19
CON*	14	16	18
LL	17	17	18
RR	15	15	17

The consistently lower values on the CONV plots are coincidental, because of the positioning of the CONV plots within the experiment.

Table 10.3.9. SAC Rotations 1 and 3: Weed numbers in untreated plots sown with the different HT and conventional cultivars in the autumn, winter and spring of year 1.

	Autumn		January		Spring	
	RI	R3	R1	R3	R1	R3
Conventional	187.5	248.5	270.5	109.5	226.5	153.0
	312.0	219.5	337.5	317.0	257.0	325.5
IMI	118.0	119.5	215.5	164.0	191.5	286.5
	269.5	165.0	398.5	277.5	318.0	152.5
Glufosinate	252.5	294.5	260.0	251.0	203.5	208.5
	340.5	283.0	256.5	264.0	210.5	249.0
Glyphosate	432.0	243.5	276.5	256.5	354.0	224.5
	206.5	247.0	389.5	348.5	275.0	386.5

10.4 Appendix 4. Summary of weed species recorded at each site

Table 10.4.1 Species recorded in different rotations at sites during the 4 years of the BRIGHT project (1998-2002)

		BB	BB	BB	MOR	MOR	NIAB	NIAB	NIAB	Roth	Roth	SAC	SAC
Scientific name	**Code**	**R2**	**R3**	**R5**	**R2**	**R3**	**R1**	**R3**	**R4**	**R1a/1b**	**R4**	**R1a/1b**	**R4**
Aethusa cynapium	AETCY		*				*	*	*	*	*		
Acer pesudoplatanus	ACEPS		*										
Elymus repens (Agropyron repens)	ELYRE	*	*	*						*		*	*
Agrostis gigantea	AGRGI									*			*
Agrostis stolonifera	AGRST									*			
Agrostis species	AGRsp					*							
Agrostis tenuis	AGRTE	*											
Allium sp.	ALLsp						*						
Alopecurus geniculatus	ALOGEN												*
Alopecurus myosuroides	ALOMY					*	*		*	*	*		
Anagallis arvensis (Androsace a.)	ANGAR	*	*	*	*			*	*				
Aphanes arvensis	APHAR	*	*	*			*	*		*	*	*	*
Arenaria serpyllifolia	ARESE	*											
Atriplex patula	ATXPA	*	*	*	*	*	*						*
Avena fatua	AVEFA		*			*	*			*			*
Avena sativa	AVESA	*		*					*	*			
Beta vulgaris	BETVU	*	*	*				*					
Brassica napus	BRANA	*	*			*	*	*	*	*	*	*	*
Brassica rapa	BRARA												*
Bromus hordeaceus	BROHO									*			
Capsella bursa-pastoris	CAPBP	*	*	*		*	*	*	*	*	*	*	*
Cardamine hirsutum	CARHI											*	
Cerastium fontanum	CERHO			*						*			
Chamerion angustifolium	CHAAN	*								*		*	*
Chenopodium album	CHEAL	*	*	*	*	*	*	*	*	*	*	*	*
Chrysanthemum segetum	CHYSE						*						
Cirsium species	CIRsp.	*	*				*		*	*	*	*	*
Cirsium vulgare	CIRVU	*	*	*			*						*
Cirsium arvense	CIRAR	*	*	*									
Convolvulus arvensis	CONAR						*			*		*	
Coronopus squamatus	COPSQ						*	*	*				
Cratageous monogyna	CRAMO			*									
Dactylis glomerata	DACGL												*
Euphorbia exigua	EPHEX						*						
Euphorbia helioscopia	EPHHE		*							*			
Euphorbia peplus	EPHPE	*		*			*						

		BB	BB	BB	MOR	MOR	NIAB	NIAB	NIAB	Roth	Roth	SAC
Scientific name	**Code**	**R2**	**R3**	**R5**	**R2**	**R3**	**R1**	**R3**	**R4**	**R1a/1b**	**R4**	**R1a/1b**
Euphorbia platyphyllos	EPHPL						*					
Epilobium hirsutum	EPIHI	*		*								
Epilobium tetragonum	EPIAD						*					
Epilobium montanum	EPIMO	*		*						*	*	*
Epilobium species	EPIsp		*				*					
Erysimum cheiranthoides	ERYCH	*				*						
Fallopia convolvulus (Polygonum c.)	FALCO (POLCO)	*	*	*	*	*	*	*	*	*	*	
Festuca sp.	FES sp.									*		
Fumaria officinalis	FUMOF		*	*						*	*	*
Galeopsis species	GAEsp											*
Galeopsis tetrahit	GALTE		*									
Galium aparine	GALAP	*	*	*	*	*	*	*	*	*	*	*
Geranium molle	GERMO	*	*									
Geranium sp.	GERsp.						*			*	*	
Holcus lanatus	HOLAN											
Holcus species	HOLCUSsp											
Hordeum vulgare	HORVU	*	*	*								*
Kickxia elatine	KICEL						*					
Kickxia spuria	KICSP						*					
Lactuca serriola	LACSE						*					
Lamium amplexicaule	LAMAM	*		*						*	*	*
Lamium hybridum	LAMHY	*										
Lamium purpureum	LAMPU	*	*	*		*	*	*	*	*	*	*
Lamium species	LAMsp.							*				
Linum usitatissimum	LINUS					*				*		
Lolium perenne	LOLPE		*									
Anchusa arvensis	LYCAR											*
Malva sylvestris	MALSI		*									
Malva species	MALsp	*	*	*								
Matricaria discoidea	MATDI		*	*								
Matricaria perforata (Tripleurospermum inodorum)	TRIIN	*	*	*								
Matricaria sp.	MATsp.	*	*		*	*	*	*	*	*	*	*
Myosotis arvensis	MYOAR	*					*			*	*	*
Odonites verna	ODOVE						*					
Papaver rhoeas	PAPRH	*	*					*	*	*	*	
Picris echioides	PICEC						*					
Phleum pratense	PHLPR			*								
Plantago major	PLAMA	*	*									
Poa annua	POAAN	*	*	*	*	*	*	*	*	*	*	*
Poa trivalis	POATR	*										

		BB	BB	BB	MOR	MOR	NIAB	NIAB	NIAB	Roth	Roth	SAC	SAC
Scientific name	**Code**	**R2**	**R3**	**R5**	**R2**	**R3**	**R1**	**R3**	**R4**	**R1a/1b**	**R4**	**R1a/1b**	**R4**
Polygonum aviculare	POLAV	*	*	*	*	*	*	*	*	*	*	*	*
Polygonum lapathifolium (Persicaria lapathifolia)	POLLA	*		*		*							
Polygonum persicaria (Persicaria maculosa)	POLPE		*		*					*		*	*
Quercus robur	QUERO		*										
Quercus species	QUEsp	*											
Ranunculus repens	RANRE						*			*	*	*	*
Raphanus raphanistrum	RAPRA	*	*		*								
Rubus fruticosus	RUBFR			*									
Rumex crispus	RUMCR	*											
Rumex sp.	RUM sp.	*		*		*				*		*	*
Rumex obtusifolius	RUMOB	*	*	*				*					*
Senecio vulgaris	SENVU	*	*	*	*		*	*	*	*	*	*	*
Silene latifolia	SILLA	*	*	*	*								
Sinapis arvensis	SINAR	*	*				*		*	*	*	*	*
Solanum nigrum	SOLNI	*	*					*	*				
Sonchus asper	SONAS	*											
Sonchus oleraceus	SONOL	*	*				*						
Sonchus sp.	SONsp	*	*	*	*		*	*	*			*	*
Spergula arvensis	SPRAR											*	*
Sisymbrium offiinale	SSYOF (SISOF)			*	*		*			*	*		
Stellaria media	STEME	*	*	*	*	*	*	*	*	*	*	*	*
Taraxacum officinalis	TAROF	*								*	*		
Thlaspi arvense	THLAR	*	*	*		*							
Trifolium repens	TRFRE			*								*	
Trifolium species	TRIsp	*											
Triticum aestivum	TRIAE						*	*	*	*	*		
Urtica dioica	URTDI											*	*
Urtica species	URTSP											*	
Urtica urens	URTUR	*	*	*		*		*	*				
Veronica arvensis	VERAR	*	*							*	*		
Veronica hederifolia	VERHE	*	*	*	*		*	*	*				
Veronica persica	VERPE	*	*	*	*	*	*	*	*	*	*		
Veronica species	VERSP	*	*					*	*			*	*
Vicia faba	VICFA						*		*	*			
Viola arvensis	VIOAR	*	*	*	*	*	*	*		*	*	*	*
Total Number of species		53	47	31	18	23	42	24	25	45	30	33	38

BB= Broom's Barn, Mor = Morley Research Centre (The Arable Group), Roth = Rothamsted Research, SAC= Scottish Agricultural College. Plant names are according to Stace (1997)

Assessments included are the autumn and spring counts and June biomass. Based on Bayer Codes

In relation to this list please note the following synonyms ( )

White campion; *Silene latifolia* (*S. alba* or MELAL)

Common couch; *Elytrigia repens* (*Elymus repens* or *Agropyron repens*) .

Black bindweed; *Fallopia convolvulus* (*Polygonum convolvulus*)

Redshank; *Persicaria maculosa* (*Polygonum persicaria*)

Pale persicaria; *Persicaria lapathifolia* (*Polygonum lapathifolium* or *P. nodosum*)

Pineappleweed; *Matricaria discoidea* (*M. matricarioides, M. suaveolens*)

Scentless mayweed; *Tripleurospermum inodorum* (*T. maritimum ssp. inodorum, or M. perforata).*

When weeds were small it was sometimes only possible to identify them to genus level, but when they became larger specific identification was possible. As a result this overall spread sheet contains both genus and species identifiers.