HGCA

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DEFINING FACTORS WHICH AFFECT THE CULTURAL AND CHEMICAL CONTROL OF BROME SPECIES IN WINTER CEREALS

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DEFINING FACTORS WHICH AFFECT THE CULTURAL AND CHEMICAL CONTROL OF BROME SPECIES IN WINTER CEREALS

by

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OVERVIEW

Barren brome (*Bromus sterilis*) became a significant weed of cereals in the late 1970s on farms where early autumn-sown crops, established by non-plough tillage, were continuously grown. While grass weed herbicides made such systems possible, they were unable to reliably control barren brome selectively in cereals. The weed remains a problem, particularly in winter cereals grown after a dry late summer/early autumn, when the shed seed is enforced into dormancy. In addition, other bromes such as meadow brome (*Bromus commutatus*) and soft brome (*Bromus hordeaceus* ssp. *hordeaceus*) have become locally important, particularly in intensive winter cereal systems. There is no reliable herbicide for the selective control of bromes in cereals and hence control measures are based on a strategy of cultural control and optimising chemical control.

Results from three related projects have more closely defined methods for the cultural and chemical control of brome species, with particular emphasis on barren brome. In addition, factors influencing the efficacy of soil- and foliage-applied herbicides on barren brome and other species have also been more closely defined.

The results of three related projects have been published in this report.

Part A - Defining factors which affect the cultural control of brome species in winter cereals

The project concluded that for barren brome:

- Although barren brome seed can survive at low levels for a year or more in the soil, depending on soil conditions and the barren brome population involved, by far the greatest danger to autumn sown crops sown in the year of shedding comes from seed which has not germinated and is not buried deeply enough to prevent emergence. This number of seeds in increased by:
  - dry autumns not allowing the seed to germinate so that they can be destroyed pre-crop sowing
  - dormant populations
  - the difficulty of ploughing all the seed below 15 cms.
  - leaving the seed on the surface too long after harvest where light restricts germination, thus reducing the time available between seed burial and sowing of the autumn crop for weeds to emergence and be destroyed

- Survival of barren brome seed in an ungerminated condition is not greatly influenced by soil type/condition, although evidence from a previous HGCA-funded project indicated that survival may be higher on clay soils.

- A small percentage of freshly shed barren brome seed survives in the soil for one cropping season but there can be sufficient viable seed to continue the infestation.

- The presence of straw does not have any effect on the survival of barren brome in the soil.

- By the time of the second autumn after shedding, the amount of rainfall, at and in the months following seed shed, does not have any effect on the seed survival over the subsequent cropping season.

- Leaving barren brome seed on the surface of the soil until the spring before burial does not increase the number of seeds surviving in a dormant condition until the autumn in the year after shedding.

Limited experiments were also done on the seed behaviour of soft brome (Bromus hordeaceus ssp. hordeaceus) and meadow brome (Bromus commutatus). These indicated that:

- It is likely that the seed burden produced by soft brome would be easier to destroy than meadow brome before the autumn crop was sown.

- There was generally no evidence of high levels of innate dormancy in either soft or meadow brome but one population out of twenty of meadow brome gave only 25% germination in the light or 20% germination in the dark after 50 days incubation.

- There were differences in the rate of germination between different populations of soft and meadow brome but generally by 50 days almost all populations had germinated in the light.

- In the dark, some populations of soft and meadow brome reach a plateau of germination after which little germination occurred, leaving a residue of seeds to form subsequent infestations. Nevertheless, light slowed down the rate of germination.

- In field experiments it was found that to maximise seed losses of most populations of soft and meadow brome through germination it was best to allow them to remain on the soil surface for at least twenty seven days before burial.

- A very low percentage of the seed of dormant populations of meadow brome could survive for one cropping season, when buried in the soil.

Experiments were also carried out to determine when cutting or treatment with glyphosate needed to be done to prevent the setting of viable seed. The conclusions were:

- Cutting should be done by six days after anthesis in barren, soft and meadow brome. As detection of this stage is difficult to assess, it is safest to cut the plants down as soon as the panicles are seen to be emerging beyond the flag leaf ligule.

- All brome species should be sprayed up to and including the soft dough stage with glyphosate.

Part B - Defining factors which affect the cultural and chemical control of brome species in winter cereals

Field experiments on the activity of soil-applied herbicides for the control of barren brome concluded that:

- A moist soil surface at the time of application resulted in higher levels of control with herbicides which need to be in the soil solution for root uptake, such as isoproturon and cyanazine.

- The moisture status of the soil surface did not affect the control achieved with tri-allate, which enters the weed as a vapour.

- The percentage control of panicles from a pre-emergence application of tri-allate was less on higher than on lower populations brome plants on a site which experienced warm autumn conditions. It is considered that this was due to strong recovery growth of survivors being able to compensate for the plant loss due to herbicides. High populations of untreated brome plants would have been severely limited in the production of panicles due to inter- and intra-specific competition.

- The depth from which barren brome emerges influences the control achieved with the selective herbicides in cereals.

Field experiments on the factors which affect the cultural control of brome species in winter wheat concluded that:

- With low/medium dormancy populations, tine or disc cultivation shortly after winter wheat harvest resulted in lower numbers of barren brome panicles in the following winter wheat crop when compared to cultivation four weeks later, provided the straw was removed at harvest. This result occurred in both a dry and a wet autumn.

- There was no advantage to early cultivation, in terms of reducing the number of panicles in the following winter wheat crop, where the brome seed was covered by dense residues of straw at harvest.

- Ploughing resulted in significantly lower numbers of panicles in the following winter crop than non-plough tillage. Timing of ploughing was only significant in the context of effectiveness of burial of the brome seed.

- There was no consistent effect of soil consolidation following stubble cultivations on brome populations in the following crop.

Part C - Adjusting pesticide dose according to leaf moisture content of the target

The project on foliage-applied herbicides confirmed that moisture supply influenced the weed control achieved, particularly at doses lower than those recommended on the product label. Various approaches to rapidly measuring moisture content or moisture stress of weeds were evaluated. Some approaches did indicate that rapid assessments

could be achieved. However, the small difference between the moisture content of moisture stressed and unstressed plants, and the practical difficulties of using these techniques in the field, suggest that new knowledge and equipment may be necessary before field guidance on dose selection based on the moisture status of the weed could be provided.

The individual projects and the authors of the final reports are as follows:

PART A
0048/1/91& 0027/1/94 - Defining factors which affect the cultural control of brome species in winter cereals

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046/1/92 - Adjusting pesticide dose according to leaf moisture content of the target

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PART A

DEFINING FACTORS WHICH AFFECT THE CULTURAL CONTROL OF BROME SPECIES IN WINTER CEREALS

ABSTRACT

The first part of the project investigated the survival of *B. sterilis* seed in soil. These investigations were prompted by findings in a previous project (Orson, 1997) that *B. sterilis* seed survived ungerminated for longer in clay soils compared with sandy soils.

In the current experiments 14,000 -15,000 seeds of either low dormancy (Pop. 41) or medium dormancy (Pop. 39) were buried at plough depth in either clay or a sandy-silty clay loam soil. No viable seed was found in the autumn of the year after shedding. Likewise, no seed was found when 15,390 seeds/m^2 of a medium dormancy (Pop. 39) seed were buried for the same period as before, in media of different pore size (sandy silty clay loam soil, fine grit 2-6 mm coarse grit, 6-10 mm or a 50/50 mix of fine grit and sandy/silty/clay loam soil). Thus, there was little further evidence to suggest that clay soil or drainage/aeration conditions in the soil have a large effect in influencing the numbers of seeds which survive in an ungerminated condition from one autumn cropping season to the next.

However, the results of the last project need to be accommodated, where the numbers of seed found in an ungerminated condition after a years' burial (even in clay soil), were only a very small percentage of the original number of viable seeds sown (maximum 0.88%). Can field experimentation detect 1 in 1,000 or 1 in 10,000. It is likely at this level, that small changes in the environment in which the seed is grown, or that exist pre-burial, or that subsequently occur in the soil, may influence the outcome of the experiment.

It must be concluded, that although survival of seed in an ungerminated condition was not greatly influenced by soil type/condition but clay soil may have favoured the longer ungerminated condition. As large numbers of seed can be shed initially (20,000 seeds from 100 plants/m^2), the survival of even a small percentage from one cropping season to another can result in serious infestations (0.88% of 20,000 seed = 176 seedlings per m^2).

To investigate the effect of straw on *B. sterilis* seed survival, a mini-plot experiment was set up in which two populations of *B. sterilis* (dormant (Pop. 34) and non-dormant (Pop. 41) one) were buried at the rate of 4,400/m^2 in sandy silty clay loam soil either with or without trash and straw. The seed was either buried in the autumn of the year of shedding or in the following spring and either kept wet or dry on the surface during the autumn. When exhumed in the second autumn after shedding the effect of burying the seed with straw did not to have any effect in enhancing or reducing the numbers of ungerminated seed which had survived ungerminated. More seed of the dormant population compared with the less dormant population survived in an ungerminated condition although survival rates were very low (0.044% compared with 0.013% respectively). As so few seeds of the low dormancy seed survived in an ungerminated condition, it was not possible to judge the effect of autumn versus spring burial on survival, but with the more dormant population there was a slightly greater survival of spring compared with autumn buried seed (0.063%

and 0.025% respectively). Wet or dry autumn conditions had little effect on ungerminated seed survival (0.04% compared to 0.05% respectively) by the second autumn after shedding.

In a field experiment 18,000-19,000 seeds/m^2 of a dormant population (Pop. 50) similar to Pop. 34 or a non dormant population of *B. sterilis* (Pop. 41) were either buried in the autumn in the year of shedding or the following spring, in a sandy silty clay loam. Very few seeds of either population (0.004% when buried in autumn or 0.003% when buried in spring) survived ungerminated until the autumn of the year after shedding. This finding was of considerable importance because it was feared from the previous project that leaving the seed on the surface of the soil during the winter would induce the seed of many populations into dormancy by moisture/light/low temperature. Once dormant and subsequently buried, this seed could have formed a seed bank which would have caused subsequent infestations.

The current project results suggest that leaving the seed on the surface of the soil until the spring before burial does not increase the number of seed surviving in a dormant condition until the autumn in the year after shedding. However, in the previous experimentation the seed was fully exposed to light and low temperature on the surface of the soil, because all seedlings and vegetation were continuously removed. This may have enabled a deeper dormancy to be induced, which would have accounted for the reluctance of the seed to germinate when placed in the dark in the laboratory at 15°C. In the current experiment, although the vegetation in the plots was periodically cut, the seeds would have been shielded from light, and from some of the low temperature effects. Thus, in areas of fields where the seed is totally exposed it may be induced more deeply into dormancy, which may allow it to survive in a dormant condition for longer when subsequently buried. This may explain why, in the mini-plot experiment on the effect of straw on seed survival, slightly more seed of the more dormant population survived into the second autumn after shedding when they were buried in the first spring compared with the first autumn after shedding. The small plots would have allowed more light/low temperature to get to the seed on the soil surface before the seed was buried.

Populations of *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* were found to have a wide range of flowering and seed shedding dates. *B. hordeaceus* ssp. *hordeaceus* populations flowered earlier than those of *B. commutatus* although there was a considerable overlap between them. In 1993 when the population had been planted on September 28/29 of the previous year, the range of flowering dates for the two species were 21 April to 26 May and 10 May to 7 June respectively. The range in the time when the populations started to shed seed was from 17 June to 17 July and from 12 July to 7 August, respectively.

All seed of the latest shedding population of *B. hordeaceus* ssp. *hordeaceus,* and *B. commutatus* had been collected by 31 July and 21 August respectively. As a consequence there was a greater period of time between the shedding of *B. hordeaceus* ssp. *hordeaceus* and the time at which an autumn cereal crop would need to be planted, compared with the period for *B. commutatus*. Thus, there would be longer for populations of *B. hordeaceus* ssp. *hordeaceus* to lose dormancy and for moisture to be available for germination, compared with populations of *B. commutatus*. Consequently, it would be likely that the seed burden produced by *B. hordeaceus* ssp. *hordeaceus* would be easier to destroy before the autumn crop was sown compared with populations of *B. commutatus*.

In laboratory tests in which seed was tested in either alternating 12 hours light and 12 hours darkness, or darkness at 15°C, there was no evidence of high levels of innate dormancy in populations of either *B. hordeaceus* ssp. *hordeaceus* or *B. commutatus* apart from in one population (out of 20) of *B. commutatus*, which in one year only gave 25% germination in the light or 20% germination in the dark after 50 days incubation. There were differences between populations in the rate of germination, both in the light and dark as shown by the percentage germination at 10 days, but by 50 days almost all population had germinated in the light. After 50 days in the dark, germination of *B. hordeaceus* ssp. *hordeaceus* ranged between 46% and 100% (1992) and 53% and 100% (1993) and for *B. commutatus* (excluding the one very dormant population) it ranged between 82 and 100% (1992) and 95 and 100% (1993). Nevertheless, light slowed down the rate of germination compared with darkness. In the dark some populations of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* reached a plateau of germination after which little further germination occurred. Such populations may pose a threat in the field because, if buried, not all the seed may germinate immediately leaving a residue of seeds to form subsequent infestations.

Emergence and germination behaviour of selected populations of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* were studied both in and on the soil surface in mini-plot field experiments. Seed placed on a moist surface immediately after shedding germinated more slowly than buried seed, confirming the results of the laboratory tests.

Nearly all populations of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus* selected to represent the range of seed dormancy types, germinated/emerged by 20 October in the year of shedding, when either left on the soil surface or buried. 20 October was taken as the date by which most autumn crops need to be sown and therefore this date gives a limit to the time that there is to rid the soil of potential weed seed propagules before an autumn crop is sown. Provided adequate moisture was available for germination, the maximum remaining percentage of seed of any population tested was 1.6%. So, the concerns from the results of the laboratory tests, that if seeds were buried immediately after shedding, large numbers of seed of some populations would persist ungerminated in the soil until an autumn crop was sown, were not vindicated. However, because very large numbers of seeds can be shed per m^2, even small percentages remaining at this latter date can result in yield damaging infestations in cereal crops sown in the autumn of the year of shedding. If moisture is not available for germination, seeds can be carried over into the autumn crop, resulting in severe infestations.

Despite the majority of populations of both *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus* having few seeds remaining viable and ungerminated by 20 October, there are some in which substantial numbers of seed remain ungerminated. In one typical experiment, 15.1% remained ungerminated by the above date when the seed was buried immediately after shedding in moist soil and 5.4% when left on a moist soil surface. Percentages are based on total germination (PBTG). Both figures were for a population of *B. commutatus*, which in general had more persistent seed populations than *B. hordeaceus* ssp. *hordeaceus*. To maximise seed losses through germination of these dormant populations seed was left on the soil surface for at least 27 days before burial. For in one experiment when this was done, no seed was recovered on 20 October in a situation where moisture was available after burial for germination to occur. In one experiment with a very dormant population of *B. commutatus*, (one population out of the 20 populations of *B. commutatus* collected) the

seed needed to be left on the soil surface for a longer period, (56 days) before burial, to reduce the number of seed remaining by 20 October to a low level (0.27% PBTG). In another experiment, if buried immediately after shedding, this population was found able to survive ungerminated until the next autumn (0.16% PBTG). This latter long-term survival of seed in an ungerminated condition was not tested in seed that had been buried at different times in the autumn after shedding, but seed of the same very dormant population certainly survived ungerminated (0.08% PBTG), until 10 January in the year after shedding, if the seed was buried 56 days after shedding.

In terms of the numbers of seed which survived ungerminated until the second autumn after shedding, tests with a moderately dormant population of *B. commutatus* revealed that there was no advantage in leaving the burial of the seed to plough depth until the spring of the year after shedding, compared with ploughing the seed down in the autumn after shedding. In both cases the numbers that survived were very low. Autumn and Spring burial giving 0.1% and 0.06% survival respectively by the following autumn. (Percentage based on original number viable seed sown).

Detailed investigations were made of the time at which seeds of *B. commutatus, B. hordeaceus* ssp. *hordeaceus* and *B. sterilis* became viable on parent plants. The seeds to first reach anthesis were those in the base of spikelets in the terminal part of panicles. Basal seeds from these spikelets were harvested at various times after anthesis and tested for viability using a Petri dish test at 15°C in the dark with the germination media containing 0.25 g/l gibberellic acid (GA_3). Seed was classified as viable if it could germinate to give a root 1 mm long. Anthesis was defined as the time at which dehiscence of the anthers had occurred in 50% or more of the basal florets. Using the above viability test, seed of *B. commutatus* and *B. sterilis* were found to become viable between 6 and 9 days after anthesis, and *B. hordeaceus* ssp. *hordeaceus* between 9 and 12 days after anthesis. Thus, seed became viable very soon after anthesis. Therefore, where cutting is used to control the viable seed production of these species, to be certain no viable seeds are produced, cutting needs to be done no later than 6 days after anthesis in all the species. A safer method would be to leave cutting no later than when the panicles are seen to be emerging beyond the flag leaf ligule. This stage is easily observed and cutting at this stage would help to allow for variation in panicle development within the field and reduce the likelihood of sufficient further seed development occurring after cutting, which could allow the seed to become viable.

Determination was made of the time of seed maturity of *B. commutatus, B. diandrus, B. hordeaceus* ssp. *hordeaceus, B. secalinus* and *B. sterilis* beyond which glyphosate no longer killed the seed. Seed viability was determined using a Petri dish test in which seed was incubated in the dark at 15°C using water as the germination media for 3 days. Thereafter, seeds were incubated under the same conditions but in 0.5 g/l gibberellic acid. Seeds were considered to be viable if they could produce 1 mm of root. When glyphosate was applied at 7.2 g ai/l to "run off" to plants of the above species up to and including the soft dough stage of the seed, all seeds were killed. When applied beyond this stage viable seeds were produced.

OBJECTIVES

1. To confirm the assessments made on the survival of different populations of *Bromus sterilis* in different soil types.

2. To determine the effect of straw on the longevity and germination behaviour of *B. sterilis.*

3. To determine the optimum period of time to leave different populations of *B. sterilis* on the soil surface to maximise seed losses.

4. To investigate the germination behaviour of *Bromus commutatus* and *Bromus hordeaceus* ssp. *hordeaceus* particularly in relation to the longevity and germinability of different populations both on and in the soil.

Objective 1

In the first project on *Bromus sterilis* funded by HGCA (Orson, 1997), there was some evidence that small numbers of the seed survived in a viable ungerminated condition for longer in clay soils compared with lighter soils. Although an extensive experiment had been set up at one site to test whether this was so, using two populations differing in dormancy status which were sown either in a clay or sandy silty clay loam soil, too few seeds were recovered after eight months burial for any robust conclusions to be drawn. A further experiment devised, to determine the survival of ungerminated viable seeds in the same two soil types.

In addition to test if survival of ungerminated viable seed depended upon the drainage/aeration of the soil, *B. sterilis* seeds of a "medium dormancy" status were buried in soils differing in pore size.

Objective 2

Now that straw/stubble burning is no longer permitted, there is a considerable residue of straw after harvest which needs disposal. It is often chopped, and then ploughed in, which gives rise to two main questions with regard to *B. sterilis* control. Firstly, what effect does the chopped straw have on the germination of the seed pre-incorporation and, secondly, are there any post-burial effects? Within this project the first question was addressed by ADAS, Boxworth, while IACR-LARS investigated the second question using a micro-plot technique.

Objective 3

In the first project, when seed of a range of populations of *B. sterilis* differing in dormancy status (from low to high) were exposed throughout the winter on the soil surface (i.e. exposed to light, moisture and low temperatures) and then recovered the following spring, it was found that all populations had been induced into dormancy.

When recovered and placed in the dark, a condition in which they would normally germinate, germination was very slow. Whether burying seeds that had been induced into dormancy by exposure on the soil surface would lead to their long term survival in an ungerminated viable condition in the soil was not known. In the current project a further experiment was set up to test this latter hypothesis.

Objective 4

Little was known concerning the dormancy/germination behaviour of either *Bromus commutatus* or *Bromus hordeaceus* ssp. *hordeaceus* when this project was started. It was considered essential to obtain such information, so that a control strategy could be formulated, particularly as there was evidence of increasing incidence of both species in cereal crops in the eastern countries of England. A total of 25 populations of *B. hordeaceus* ssp. *hordeaceus* and 20 populations of *B. commutatus* were collected during the course of the project, grown under common environmental conditions at Long Ashton and then tested for germination behaviour in the laboratory. Selected populations were tested outdoors in six mini-plot experiments to determine their germination and longevity behaviour in the field, particularly in relation to timing of autumn burial.

OBJECTIVE 1 - FIELD TESTS USING MINI-PLOTS TO INVESTIGATE THE BEHAVIOUR OF DIFFERENT POPULATIONS OF *B. STERILIS* SEED IN SOIL

Experiments concerned with the survival of different populations of *B. sterilis* in different soil types.

EXPERIMENT 1

Methods

Two populations of *B. sterilis* (Pop. 41 LARS stock-bed low dormancy and Pop. 39 Boxworth medium dormancy) were grown in stock-beds at LARS. Seed of Population 41 was collected on 22 July and buried on 23 July 1991 and seed of Population 39 collected on 29 July and buried on 31 July 1991. Because the seed needed to be planted very quickly after collection it was not possible to assess seed viability which would have enabled an exact number of viable seed to be planted. Instead, 5 gram samples of seed were used to determine the 1000 grain weight and then the weight of 3,034 seeds of each population calculated. Batches of 3034 seeds of each population were then weighed out. One batch of seed, of each population was separately planted in a freely draining plastic tray 36 x 56 cms x 7.5 cms deep (3,034 seed equivalent to 15,000 seed per m^2). The seed was planted in either a heavy clay soil or a sandy silty clay loam soil. The seed was sown 3 cm deep in each box, and then the boxes were buried in their respective soil types, so that the layer of seeds was at a final depth of 20 cms. There were 4 replicates arranged in a randomised block. The percentage viability of the seed that was planted was assessed at a later date, so that the actual number of viable seed that had been planted could be determined.

All the trays were exhumed on 22 October 1992 (16 months after burial). The contents of each tray were spread out approx 2.5 cm deep and blow dried over a period of 2-3 days.

The soil was then re-wetted and wet sieved to extract any remaining *B. sterilis* seed. The viability of the seed in the final soil seed residue was determined by traying out the residue and observing for seedling emergence. After 5 months the soil was treated with 1 g/l of gibberellic acid to stimulate any remaining seeds to germinate.

Results

The viability test on the planted seed showed that seed of population 41 was 99.3% and that of population 39 was 91.5% viable. This meant 3001 seeds per tray of population 41 and 2782 per tray of population 39 had been planted, equivalent to 14,888 and 13,725 viable seeds per m^2 respectively.

Out of all this seed not a single viable seed was recovered from either population buried in either soil type after exhumation on 22 October 1992.

Discussion

Seed of a low or medium status dormancy population of *B. sterilis* did not remain viable from one autumn cropping season to the next autumn cropping season in either a heavy clay or sandy silty clay loam soil.

EXPERIMENT 2

To determine if survival of ungerminated viable seed of *B. sterilis* depends upon the drainage/aeration of the soil.

Methods

Seed of *B. sterilis* (Pop. 39, medium dormancy) were pot grown and collected on 20 July 1993. As in experiment 1 the 1000 grain weight was determined and from this the weight of 2000 seed was calculated. Batches of 2000 seeds were then weighed out and one batch sown in each of the following soil types:-

- Sandy, silty clay loam soil.
- Fine grit 2-6 mm.
- Coarse grit 6-10 mm.
- 50/50 mix of fine grit (2-6 mm) and silty clay loam.

The soils were contained separately in very large pots (50 litre). The seeds were sown 20 cm deep in the pots and then the pots were buried so that the soil within the pot was level with the surrounding soil. There were four replicates arranged in a totally randomised block design. Samples of the original seed that was planted were subsequently tested for viability, so that the total number of viable seeds planted could be calculated.

In November 1994 (total time of seed burial = 16 months) the whole contents of each container was separately wet sieved to retrieve any remaining seed. In the case of the gravel treatments large bulks of gravel could not be separated without the risk of seed loss or damage, so these were specially washed over a sieve and any remaining seed removed by

hand. Viability of the seed was then determined by addition 500 ppm of gibberellic acid GA_3 to the seeds in Petri dishes incubated at 15°C in the dark. In the case of the soil treatments, the soil residue after sieving was trayed out and any seedling emergence counted. After 3 months the trays were treated with 1 g/l gibberellic acid (GA_3) and any further emergence noted.

Results

The total number of viable seeds planted initially per tank and therefore per soil type was 2082, which is equivalent to 15,390 per m^2. Out of these seeds no viable was retrieved from any of the soils after the 16 months burial. However, in the fine, grit and coarse grit treatments when the seed was retrieved from the exhumed samples, a total of five seeds (all replicates combined) from the fine grit and one seed (all replicates combined) from the coarse grit were retrieved. It was noted that the embryos of all these seeds were dead, but that the endosperms were intact.

Discussion

Within the range investigated (which was designed to be very wide) the pore size/soil aeration of the soil did not differentially affect the survival of a medium dormancy population of *B. sterilis* seed in a viable condition as shown by exhumation and germination tests after 16 months.

OVERALL DISCUSSIONS AND CONCLUSIONS CONCERNING THE BURIAL OF B. STERILIS SEED

A series of field experiments has now been done on the survival of viable *B. sterilis* seed in soil. These experiments have involved the burial of large numbers of seed and the sieving of very large quantities of soil to retrieve any ungerminated seed. It is therefore pertinent to review the results of these experiments.

Previous experimentation (Orson, 1997)

In the very first LARS experiment using population 41 (which is a standard low dormancy (LD) population as found on many farms) very few seeds (0.075%) survived even until the autumn when buried in a sandy loam after shedding in August. When the plots were exhumed the following spring, no viable seed was found.

In a second experiment (SAC) in which 10,000 seeds per m^2 of population 41 (LD) and 39 (medium dormancy MD) were buried at different depths (5-20 cms) in a sandy loam soil, no viable seed of population 41, was found at or after one years burial. Whereas, a maximum of 0.06% of seed of the medium dormancy population (39) was found after 1 year and none was found after two years. In a third experiment the same populations were set up (at Boxworth) in an identical experiment to that set up at SAC, except that the soil type was heavy clay. After one and two years burial the greatest percentage of population 41 surviving ungerminated was 0.53% and 0.06% respectively, and that of population 39, 0.88% and 0.06% respectively.

The results of the SAC experiment and the LARS experiment supported each other in so far as population 41 was behaving similarly at both sites, although no comparison of population 39 could be made because it was not planted in the LARS experiment. At Boxworth seed of both populations could survive, albeit at low numbers, for at least 2 years, with the first years results showing that the higher dormancy population was surviving in slightly higher numbers. The conclusion was reached that possibly the soil type was responsible in some way for greater survival, because at Boxworth the soil type was heavy clay, whereas at LARS and particularly SAC the soil was of a much lighter type. The results at Boxworth were treated with some caution because a slightly different burial technique to the other sites was used, but a further experiment to test if the different technique in clay and sandy soil were having an effect on seed survival showed seed survival after 8 months was very low (max. 0.017%) when using either technique. Again seed survival overall was very slightly greater in the clay compared with sandy soil. On this occasion only seed of population 41 (LD) survived ungerminated after 8 months compared with none in the higher dormancy population 39.

Current Project

No seed of either population 41 or 39 was found after 16 month burial, in either clay or sandy silty clay loam soil (original number of seeds planted was 14-15,000 seeds per m^2). Nor was any seed found of population 39 after it had been buried for the 16 months in soils of very differing pore size.

What conclusions can be drawn from these experiments? The first is, that after a years burial very low numbers of seeds of any population remain viable and ungerminated in the soil. The second is that because the numbers of seeds remaining, particularly after a year or slightly longer, (which of necessity is the unit of time required to see if the seed will survive ungerminated from one cropping season to another) the detection of these very small numbers is experimentally very difficult.

It is difficult to envisage the experimentation required to detect one in 1,000 or even one 10,000 seeds. Probably just a small change in soil conditions or in the condition of the seed pre-planting may greatly influence the outcome of the experiment. In the current project in experiment 1, the seed was planted immediately after collection, because in this way, it was hoped to sow the seed at its maximum level of innate dormancy. Yet, no seed was found to be viable after 16 months burial in either clay or sandy silty clay loam soil, whereas previously in the Boxworth experiment small numbers of viable seed were recovered after 2 years burial in clay soil.

However, in the current project because no viable seeds were detected after one years burial in either clay or the lighter loam soil or in soil media differing in pore size/aeration, it must be concluded that soil type or soil aeration/drainage has a relatively small effect on viable seed survival. Nevertheless, it must be remembered that even a low percentage survival rate is very important, because the initial number of seed shed can be very large e.g. up to 20,000 seeds can be shed from 100 plants/m^2 and 0.88% (max. survival of Pop. 39 in the Boxworth experiment) represents 176 plants m^2. Small differences at low-survival rates can therefore be very important.

It is clear, that at the very low levels of survival which are involved, the results will be variable. The conclusions arrived at in the first project must therefore still stand as an insurance against worst case scenarios. These conclusions are as follows:-

- For the majority of populations found in England burial of the seed in the autumn to plough depth should result in nearly all the seed being lost from the lighter soil types (mainly through germination and non-emergence) by the second autumn after shedding.

- There are a few populations which possess greater dormancy characteristics which can allow seed to last up to a year in lighter soils.

- There are certain environmental conditions which affect the seed during maturation or pre-burial, or soil types/conditions, which can lead to the survival of buried seed of both low and high dormancy populations in large enough numbers after one year to cause serious infestations and after 2 years to cause minor infestations.

- It is essential to bury all the seed to a depth of 15 cms when ploughing, otherwise any seed left of the soil surface will be incorporated into the soil by pre-drilling cultivation in the autumn. These incorporated seed will then germinate from a depth from which they can emerge and produce a major infestation. With populations easily enforced or induced into dormancy by light there could be large numbers of seed left on the soil surface. The greater the number of seed left on the soil surface by the time of ploughing in the autumn, the greater the difficulty of burying all the seed. This is mainly because the long awns on the seed tend to matt the seed together making it difficult to incorporate without some seed springing loose on to the previously ploughed land. Slow rather than fast ploughing is to be recommended.

OBJECTIVES 2 & 3 - AN EXPERIMENT TO DETERMINE THE EFFECT OF BURYING *B. STERILIS* SEED WITH STRAW ON THE LONG TERM SURVIVAL OF THE SEED IN A VIABLE UNGERMINATED CONDITION.

Methods

Seed of two populations of *B. sterilis* (Pops. 41 LD and 50 HD) were grown in stockbeds. Seed of population 41 was collected on July 22 1991 and that of population 50 on 16 August 1991. Barley straw and trash for the experiment was collected from a freshly harvested field on 17 July 1991. The experiment was set up in 64 large rectangular pots 42 x 27 cms filled with a sandy silty clay loam soil to within 1.0 cms of their rims. Two centimetres of 2.0 cm. diam. gravel was placed in the bottom of each pot and covered with 1.0 cm of coarse peat to promote drainage. The pots were then buried so that the soil within the pot was level with the soil in the surrounding area. The base of the pots had drainage holes, and the base sat on a layer of peat overlaying gravel to promote drainage.

The surface of the soil in half the number of pots was sown with 500 seeds of population 41 (sown 26 July 1991) and the remaining half with 500 seeds of population 50 (sown 16 August 1991). The seed in half the number of pots in each population was buried in the

autumn (Population 41 was left on the surface for 42 days and buried 6 September 1991, and Population 50 was left on the surface for 49 days and buried 4 October 1991). The seed in the remaining pots of each population was buried the following spring (21 April 1992) (Population 41 was left on the surface for 270 days, and Population 50 was left on the surface for 249 days). Half the number of pots in each population were kept dry up to the time of their first burial by placing polythene covers over the pots when rain was imminent or during actual rainfall.

After autumn burial all the seeds that had been kept dry were watered once (i.e. seed buried in the autumn and seed remaining on the surface until the spring burial) and then left to be subjected to natural rainfall. The soil in the remaining pots (half the number of each population) was kept moist (this applied to both the seed to be buried in the autumn and to that to be buried in the spring) up until the autumn burial date. Thereafter, this latter seed was subject to natural rainfall. In addition, straw and trash were added to half the pots of each population at the time when the seed was sown. To ensure that the amount of straw and trash covering the seed was similar to that in the field, sample 1 metre quadrats were placed in the swathe of straw/trash left by the combine harvester in the field. The straw and trash in the samples were dry weighted at 100°C to obtain the dry weight of both the straw and trash per m^2. The weight of trash added to the surface of the soil (after the seed was sown) was added at the same weight per m^2 as in field. The weight of straw added per m^2 in the pots was adjusted compared with that in the field, because it was assumed that the straw would be chopped and equally dispersed across the field.

The width of bare ground between swathes of straw was approximately the same width as that of the straw swathe. As a consequence the weight of straw added per m^2 to the pots was therefore halved. The weight per m^2 of trash added to the pots was not adjusted because it was considered that the trash would not be moved from its original position in the field. The moisture content of both straw and trash was measured separately immediately before placement, so that the correct weight of each could be added to the pots (i.e. air-dried straw and trash was used). All the pots were protected throughout the experiment from birds and mice. All treatments were replicated 4 times and laid out in a randomised block design. Germinated seedlings were removed from all the treatments throughout the experiment apart from those in the straw treatments in which the seedlings were carefully cut off as short as possible with scissors. Removal of seedlings from the straw treatments would have been very disruptive to the treatment.

At burial in the non-straw treatment all seeds together with the top 2.5 cms of soil was removed from the pot. A further 17 cms of soil was then removed from each pot. The seed plus soil fraction removed was then replaced at a depth of 17 cms. The pot was then refilled to within 1 cm of its rim with the other soil removed previously from the pot.

At burial in the straw treatments, the straw was removed from the surface of the soil and then the procedure was the same as for the non-straw treatments. Except, that the straw was placed on the surface of the soil in the pot when the main bulk of soil had been removed. The seed and 2.5 cms of soil was then placed on top of this straw before the pot was refilled with soil. The straw and seed were buried in this way to simulate, the placement of straw in the field after ploughing.

The viability of the original seed planted was tested in the laboratory so that the exact number of seeds planted could be determined.

The pots were exhumed between 11 November and 23 November 1992. Total burial time for Pop. 41 autumn burial = 438 days, spring burial - 210 days, and for Pop. 50 autumn burial = 410 days and spring burial = 210 days.

The entire contents of each task was then subject to a wet sieving process. To determine the number of seeds remaining viable, the remaining soil seed residue was trayed out and observed for seedling emergence for 4 months. Then, each tray was treated with 1 g/l of gibberellic acid (GA_3) to stimulate the germination of any remaining viable seed.

Results

The number of ungerminated viable seeds recovered from the soil in the autumn following either burial in the previous autumn or spring are given in Table A1 below.

Discussion

The seed in the experiment was kept either wet or dry during the period between harvest (i.e. sowing the seed on the soil surface and the time of burial in the autumn) to simulate either a dry or wet autumn, because it was considered that the moisture may not only have had an effect on the germination of the seed but also on the straw and its micro environment. This in turn could have affected the number of ungerminated viable seed. Because of the low numbers of seeds recovered no formal statistical analysis could be applied to the data. Although the number of seeds recovered in the autumn following burial in either the previous autumn or spring are very low there is a hint that wet conditions may be favouring less seed survival (Table A2). This would seem sensible because wet conditions should be more conducive to germination and seed rotting during the period in the autumn before burial. Likewise, although numbers of seed recovered were very small, the numbers of seed of population 50 that survived ungerminated were greater than those of population 41. This was the largest overall effect in the experiment and could have been expected because population 50 was the more dormant of the two populations as judged by the amount of dormancy that can be induced in either population by light. There was no indication that the presence of straw was affecting the long term survival of the seed. Likewise, there was no effect of a difference in the timing of the burial of seed (autumn or spring) on viable seed survival (Table A2). However, there were slightly greater numbers of seed remaining after spring burial compared with autumn burial of population 50. (1.1/m^2 autumn 11.01/m^2 spring) which may be indicative that with more dormant populations, dormancy can be induced in the winter by cold/light waterlogging.

It can be concluded that:

- No large effect of the presence of straw under either wet or dry autumn conditions on the survival of seed of *B. sterilis* from one cropping season to another could be detected.

- Wet conditions in the autumn after harvest possibly lead to greater losses of viable seed of *B. sterilis* by the time of the following autumn.

- The inherent dormancy status of a population of *B. sterilis* (as judged by its ability to be enforced/induced into dormancy by light) has an effect on the long term survival of the seed in a viable ungerminated condition from one cropping season to another. Those populations with greater dormancy potential giving rise to greater numbers of surviving seed.

- As this was the first experiment in which the effect of straw on long term survival of *B. sterilis* seed was treated, further experiments should be carried out to obtain a robust answer.

- As very small numbers of seed were found in either the straw or no straw treatment (or any treatment) after the period between initial seed shed and the autumn of the year after shedding, it is unlikely that any of the factors investigated would allow large numbers of seed to pass from one cropping season to another.

OBJECTIVE 3 - AN EXPERIMENT TO INVESTIGATE AUTUMN VERSUS SPRING BURIAL OF *B. STERILIS* SEED ON THE SUBSEQUENT SURVIVAL OF VIABLE UNGERMINATED SEED.

Methods

Seed of *B. sterilis* populations number 41 (low dormancy) and 34 (high dormancy) were pot grown and collected between 6 and 16 July 1993. 1,000 grain weights were obtained for each population to allow the weight of 15,000 seeds of each population to be weighed out. This number of seed was sown on the surface of field plots 90 x 90 cms containing sandy, silty clay loam soil. (Seed rate equivalent to 18,519 seeds per m^2). After correction for seed viability determined later in the laboratory, the number of seed planted of population 34 was 15,330 viable seeds per plot (18,926 per m^2) and of population 41 14,929 viable seeds per plot (18,431 per m^2). The seed was protected from birds and mice and slugs. The seed was left on the surface and either buried on October 18 1993 (90 days on surface) to simulate autumn burial and on 9 May 1994 (293 days on surface) to simulate spring burial).

The vegetation in all the plots was cut off on 7 September 1993 and before each burial date. When the seed was buried, the top 8.0 cms of soil/seedlings/seed was removed as turves. The plot was dug out to a depth of 30 cms and the turves inverted and placed at a depth between 22 and 30 cms in the plot. To help relocate the position of the seed in the soil a 10 cm band of aluminium was placed around the edge of the plot at turf depth. In addition a piece of plastic weld mesh was placed above and beneath the turves. All treatments were replicated four times and the experiment was laid out in a randomised block design.

All the plots were exhumed between 5 and 16 December 1993. To determine the number of seeds remaining ungerminated and viable, the soil was wet sieved, and the residue trayed out and the trays observed for *B. sterilis* seedling emergence. After 3 months the trays were treated with 1 g/l ppm gibberellic acid to stimulate any remaining ungerminated viable seed into germination.

Results

The results of the experiment are presented in Table A3.

Discussion

The main reason for setting up this field experiment was that in the previous HGCA project (Orson, 1997) it was found that *B. sterilis* seed of many different populations were induced into dormancy if left on the soil surface during the winter. It was therefore of some considerable concern that if seeds of this species were left on the surface during the winter, and then buried in the following spring, they may form a considerable ungerminated bank of seeds in the soil which would then be available for subsequent germination and infestation of crops, particularly those planted in the following autumn.

The results of the present experiment show that the numbers of seed surviving in an ungerminated viable condition until the autumn in the year after the year of shedding, when buried to plough depth either in the autumn of the year of shedding, or in the following spring were very low (Table A3). This applied to both a low dormancy population (41) and a high dormancy population (34). So, it would appear that there is no great risk in leaving the seed on the soil surface during the winter and then burying it in the spring of the year immediately after the year of shedding. However, the original experiment was done in small outdoor plots in which all the seedlings and therefore any vegetation growth was removed throughout the experiment. This meant that the remaining seed on the soil surface was exposed to full sunlight during the winter, whereas in the current experiment the seed was covered in a swathe of seedlings and other weed germination, as it would be in a normal field situation if it was left uncultivated.

The vegetation was periodically cut over to simulate the effect of cutting in the field, but nevertheless the seed would not have been exposed to full sunlight. This may explain the differences between the two experiments, because in the current experiment, as the seed was not continually exposed to full sunlight, it may not have had a high level of dormancy induced in it before spring burial. Therefore, when the seed was recovered the following autumn, little difference was found between the survival of seed buried either the previous autumn or spring. Nevertheless, there still needs to be caution, because not all of the seed left on the surface of the soil in a real field situation may be covered with vegetation during the winter. It would therefore still be better practice to bury the seed before the winter, and preferably before 3 months had elapsed after shedding as found in the previous project.

It should be noted that this was the first field experiment at LARS in which the low dormancy population 41 had survived (albeit at very low numbers) for just over a year in an ungerminated condition in sandy silty clay loam soil. The conclusions regarding seed survival of low dormancy seed in this type of soil as suggested in the previous project will need some modification.

It can be concluded that:

- Very few seeds (0.002 to 0.005% of viable seed sown) of a dormant or non dormant population of *B. sterilis* were found to survive until the autumn of the year after the year of seed shed. This applied where the seed was either buried to plough depth in the year of shedding or in the subsequent spring. Caution is necessary in this conclusion, because this conclusion may only apply to situations in which seed on the soil surface is covered by vegetation.

- Seed of the non dormant population 41 can survive at plough depth from the autumn of the year of shedding with the next autumn i.e. from one autumn crop sowing to the next.

OBJECTIVE 4 - LABORATORY INVESTIGATIONS INTO THE GERMINATION CHARACTERISTICS OF DIFFERENT POPULATIONS OF *BROMUS COMMUTATUS* AND *BROMUS HORDEACEUS* SSP. *HORDEACEUS.*

Experiments concerned with the germinability of various populations of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus:*

Experiment 1 harvest year, 1992;
Experiment 2 harvest year, 1993;
Experiment 3 harvest year, 1994.

Methods

A total of 20 populations of *B. commutatus* from 15 farms and 25 populations of *B. hordeaceus* ssp. *hordeaceus* from 21 farms were collected from various sites from southern England northwards to and including Yorkshire over a three year period. Each year the seed from the original sites were sown in pots (planting dates were: 8 November 1991; 28 September 1992; and 9 November 1993). Not all the populations were grown each year.

The pots (27 cm diam) contained soil composed of 3 parts loam, 2 parts peat, 1 part Cornish grit with 5 grms per litre of osmocote 8-9 month slow release fertiliser and 3.3 grams of magnesium limestone. In 1993 the ratio of grit and peat was changed to 1.5 parts of each.

In each of the years the flowering date of each of the populations was recorded. The flowering date was defined as the date at which the spikelets were first seen to break out of the top most sheath of a plant within a given population. Seed was collected from the panicles on the plants when the seed started to shed naturally. The seed was collected by gently stroking the panicles. In 1992 and 1993 the seed was collected over a period of 14 days, during which the collected seed was stored outdoors, at ambient temperature but protected from rain and direct sunlight.

The seed was then brought indoors for one week to dry all populations of seed down to approx. 12-15% moisture content. In 1994 the seed was collected over a shorter period (7 days), and dried down for 5 days. Four reps of 100 "full" seed were then counted out from each population and set up separately in 9.0 cm Petri-dishes containing 1 glass-fibre and 3

Whatman No.1 filter papers with 8 ml de-ionised water. One set of dishes was incubated in the dark and another set in a 12 hr light/12 hr dark regime at a temperature of 15°C. Germination was recorded at 3-7 day intervals until germination was complete or had ceased for several weeks. The viability of the remaining ungerminated seed was determined by transferring the seed on to fresh filter papers moistened with 8 ml of 0.5g/l gibberellic acid (GA_3) and recording any further germination.

Results

The results of the dates of flowering of the various populations of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus* are given in Table A4. It is not possible to directly compare the flowering dates in 1993 with those of 1992 and 1994 because the date of planting was 40 days earlier in 1993. It should be noted that in 1993 the planting date was nearer the normal planting date of autumn sown cereals than the planting dates in 1992 and 1994, so the results of the flowering and shedding in 1993 would be the most representative of the natural situation. In 1993 the dates of flowering of the populations of *B. hordeaceus* ssp. *hordeaceus* ranged from April 21 to May 26 whereas for *B. commutatus* they ranged from May 10 to June 7. However, despite the large difference in planting dates between 1992, 1994 and 1993, if the earliest flowering population (planted in each year) of *B. hordeaceus* ssp. *hordeaceus* (H2) is taken, the time of flowering in 1992 and 1993 only differed by 16 days and between 1993 and 1994 by only 8 days. Likewise, if the earliest flowering population (planted each year) of *B. commutatus* (C2) is taken, the time of flowering between 1992 and 1993 differed by 4 days and by 3 days in between 1993 and 1994. Clearly plant maturation is speeded up when the seed was planted in late autumn.

Generally the populations flowered in the same sequence each year, although there were some exceptions. One main feature was that in each year the bulk of the populations of *B. hordeaceus* ssp. *hordeaceus* flowered before those of *B. commutatus*, the dates of the main periods being May 10 to 27 and May 26 to June 12 respectively.

An earlier flowering population naturally led to an earlier seed shedding population compared with a late flowering one, e.g. in 1993 population H6 (*B. hordeaceus* ssp. *hordeaceus*) was the earliest one to flower (21 April) and the earliest to shed (17 June). Whereas, population C6 was one of the latest flowering (12 June) and one of the latest to shed (7 August).

Clearly, later shedding populations will need very little dormancy in their seed for them to become a serious weed problem. With late shed populations the time interval between shedding and sowing the autumn crop will be very short, and this will allow little time for dormancy to be lost or for moisture to arrive to enable germination to occur. Consequently, many ungerminated seeds will be available to infest the autumn sown crop.

From this, it follows that populations of *B. hordeaceus* ssp. *hordeaceus* (unless they are very dormant) are less likely to provide serious infestations of autumn sown crops compared with populations of *B. commutatus* because generally populations of *B. hordeaceus* ssp. *hordeaceus* tend to shed earlier than those of *B. commutatus*.

The results of the germination behaviour of each individual population in the light and dark at 15°C are not presented because of the large volume of data involved. To summarise the

data, graphs of the per cent germination of viable seeds of each population were prepared using genstat. Using these graphs, the percent germination that had occurred in each population by 10, and 50 days after imbibition was then determined, and presented in Figures A1 to A4. The two dates were chosen because they illustrated the germination in the light and dark at an early and late stage in the experiments. In 1992 and 1993 the populations grown and tested were not selected and therefore represent a random selection that may be obtained when collections are made from British fields. In 1994 the populations grown and tested were selected for particular dormancy traits. Most of the emphasis of the results is therefore placed on the 1992/93 data.

The 1992 and 1993 data show that although germination in a number of populations of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* is slow particularly in the light as shown by the germination at 10 days compared with that at 50 days, few populations show high levels of innate or enforceable dormancy as shown by the germination at 50 days. For example, in the case of *B. hordeaceus* ssp. *hordeaceus* in 1992, out of the 22 populations tested 7 populations had totally germinated in the light and 10 in the dark by 10 days, whereas by 50 days 18 populations had fully germinated in the light and 11 in the dark. (All populations gave 90% germination in the light and 18 populations 90% germination in the dark at 50 days).

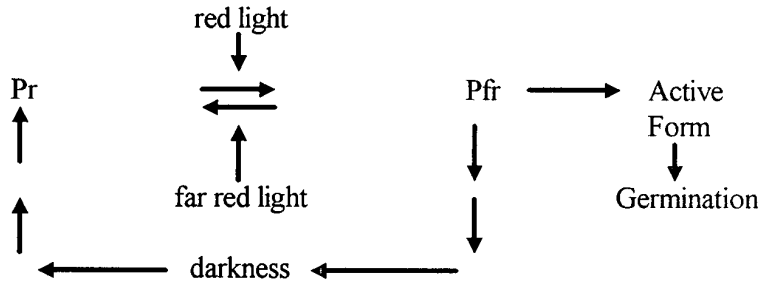
In the case of *B. commutatus* in 1992, out of the 17 populations tested 10 populations had totally germinated in the light and 12 in the dark by 10 days, whereas by 50 days 16 populations had fully germinated in the light and 13 in the dark (90% germination was given by 16 populations in the light and 14 in the dark at 50 days). Similar trends in the data occurred in 1993.

Therefore in populations of both species, although germination was slower in the light than in the dark, more populations reached complete germination in the light in 50 days than they did in the dark.

The relative slowness of germination in the light compared with the dark is seen in 6 out of the 22 population of *B. hordeaceus* ssp. *hordeaceus* in 1992 in which there is 10% less germination in the light compared with in the dark after 10 days of incubation. Likewise in 1992 the same reduction of germination in the light is given by 3 out of 12 populations of *B. commutatus*. It must be said that there were also two populations of *B. hordeaceus* ssp. *hordeaceus* and one of *B. commutatus* which germinated to a greater extent in the light (populations H7, H11 and C2). However, in two further years (1993/94) of testing each of these populations followed the trend of the other populations by giving less germination after 10 days in the light compared with the dark.

Further evidence of the slowness of germination in the light can be seen from the 13 populations of *B. hordeaceus* ssp. *hordeaceus* (1992) which germinated to a less extent in the light after 10 days, but after 50 days, the germination in all but one population had either overtaken or equalled the germination in the dark. The same applied to *B. commutatus* (1992) in which six populations showed less germination after 10 days incubation in the light, but which had all either exceeded or equalled the germination in the dark at 50 days. The same trends were apparent with both species in 1993 and 1994.

One important feature of the germination of some populations of both *B. hordeaceus* ssp. *hordeaceus* and to a less extent *B. commutatus* was that they germinated to a given level in the dark and thereafter little further germination occurred. Whereas, very often with these populations, as we have seen previously, although germination in the light is slow, by 50 days it has caught up and exceeded the germination in the dark. As an example, of this behaviour, if the 1992 populations of *B. hordeaceus* ssp. *hordeaceus* incubated in the dark are considered, 10 of these show less than a 10% change in germination between 10 and 50 days after inhibition. Similar trends could be seen in the 1993 data. This feature was less evident in the *B. commutatus* data with only 2 out of 17 populations in 1992 showing this trait. Similar trends could be seen in the data for 1993 and 1994. An illustration of this germination behaviour is given in Figure A5 clearly showing that germination occurs to a given level in the dark, and thereafter and level of germination plateaus out with little further germination occurring until the germination stimulant GA_3 is added. This behaviour could be interpreted using the classical phytochrome response.



When the seeds were shed there may have been some seeds with a sufficient residue of phytochrome in the Pfr form to allow germination to occur when the seeds were subsequently imbibed. However, in other seeds, there may have been insufficient Pfr to allow germination, or any that was present could have been converted back to the Pr form of phytochrome in the dark, thereby preventing germination. Whereas in the light, sufficient Pfr was available to allow germination to occur. Further experimentation would be needed to justify this hypothesis, but it seems highly likely that the phytochrome system is responsible for this trait in the germination behaviour.

Clearly, in the field these latter populations may pose a threat to crops, because once buried in soil (and therefore in darkness) a portion of the population may not germinate immediately, and therefore have the potential to germinate at a later date in a subsequent crop. The field experiments were designed to determine if this latter finding was of importance in the field.

One population of *B. commutatus* was found which was highly dormant in both the light and dark Figures A1, A2 and A6. In this population large numbers of seed were still ungerminated both in the light and dark after 50 days, so this population would represent a very difficult population to control culturally.

It can be concluded that:

- Populations of *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* have a wide range of flowering dates. In those investigated, (when sown at a time when autumn crops were sown) the flowering dates for *B. hordeaceus* ssp. *hordeaceus* were 21 April to 26 May and for *B. commutatus* 10 May to 7 June. Earlier flowering times led to earlier shedding times. The earliest flowering population was a population of *B. hordeaceus* ssp. *hordeaceus* which started to shed seed on 17 June. Whereas the latest population to flower was one of *B. commutatus* and this started to shed on 7 August.

- Extrapolating conclusion one above into the field: as populations of *B. hordeaceus* ssp. *hordeaceus* shed earlier than those of *B. commutatus*, there is a longer time for seed of *B. hordeaceus* ssp. *hordeaceus* to loose dormancy and for moisture to become available to them for germination. This should allow more seed of *B. hordeaceus* ssp. *hordeaceus* compared with *B. commutatus* to be lost from the soil due to germination prior to planting an autumn crop in the year of shedding, making *B. hordeaceus* ssp. *hordeaceus* less of a control problem.

- Apart from one population of *B. commutatus* there was little evidence of high levels of innate dormancy in any of the populations of *B. hordeaceus* ssp. *hordeaceus* or *B. commutatus* investigated. All the latter populations almost completely germinated in the light after 50 days incubation at 15°C.

- The presence of light slowed down the rate of germination in populations of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus.*

- In the dark some populations of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* reached a plateau of germination, after which little further germination occurred. These populations may pose a threat, because if buried immediately after shedding, not all the seeds may germinate, leaving a residue of seeds to form infestations in subsequent crops.

- One population of *B. commutatus* was found in which little germination occurred in the light or dark. This population would represent a severe threat to autumn cereal growing.

OBJECTIVE 4 - OUTDOOR MINI-PLOT TESTS TO INVESTIGATE THE BEHAVIOUR OF *B. COMMUTATUS* AND *B. HORDEACEUS* SSP. *HORDEACEUS* BOTH IN AND ON THE SOIL SURFACE

EXPERIMENT 1

A preliminary experiment to investigate the germination of two populations of *B. commutatus* and two populations of *B. hordeaceus* ssp. *hordeaceus.*

Methods

Seed of two populations of *B. commutatus* (C1 and C2) and two populations of *B. hordeaceus* ssp. *hordeaceus* (H1 and H2) were pot grown as described for the seed used in the laboratory tests. The stock-pots were planted on 21 November 1990 and seed from populations H1, H2 and C2 collected between 29 July and 2 August and planted on 6 August 1991. Population C1 was collected on 15/16 August and planted on 21 August 1991. All pots were watered 1-2 days after sowing and kept moist thereafter. Between collection and storage the seed was kept dry at ambient temperatures out of direct sunlight. Two hundred "full" seeds of each population and each species were separately sown at 2.5 cms in 23 cm diam. pots. One thousand "full" seeds of each species and each population were also separately sown in 23 cm diam. pots and either buried at 20 cm depth in the pots or left on the surface until 26 November when it was intended for any remaining seed to be buried at 20 cms in the pots. But as all seed had germinated in this treatment no seed could be buried. Only 200 seeds were planted at 2.5 cms because any greater number would have caused a great deal of soil disturbance, both during emergence and during seedling removal, which may have influenced the emergence behaviour due to the ingress of light into the soil. There were four replicates laid out in a randomised block design. The pots were buried outdoors in soil so that the soil within the pot was level with the surrounding soil. The pots were protected from large and small mammals, birds, and slugs. Emergence was recorded, and any emerged or germinated seed removed.

All pots that had seed initially buried at 20 cm. or that possibly contained ungerminated seed were exhumed on 31 October 1992, 16 months after setting up the experiment (i.e. from shedding in one cropping year to autumn in the following year) and the soil wet sieved to recover any remaining seed. The soil/seed residue was placed in trays and the emergence recorded. To stimulate all further remaining seeds into germination and thus detect any remaining viable seeds, on 8 March 1993 all trays were treated with 400 ml of 1.0 g/l of gibberellic acid (GA_3). The per cent seedling emergence based on the total number of seedlings emerged for the first two dates of recording for the 2.5 cm and surface treatments were statistically analysed. There was too little seedling emergence to allow analysis at other dates.

Results

The results of the emergence from 2.5 cms and the germination of the surface treatments are given in Figures A7a and A7b and Table A5. No emergence occurred from 20 cms.

Germination when buried was more rapid than when the seeds were left on the surface, particularly in population C1. However, if left in the light all populations including the most dormant population C2, reached 100% germination by 26 November 1991. Whereas, when buried at 2.5 cms, (i.e. kept in the dark), although all seeds of population H1 and H2 germinated by 26 November 1991, a small residue of seeds of both C1 and C2 remained (Figure A7a). In the case of C2, these seeds remain dormant (0.16%) until the following autumn (31 October 1992), so this particular population can remained dormant in the soil (when buried immediately after shedding) from one autumn cropping season to another. No seed of any population originally buried at 20 cms was found to be viable on 31 October 1992.

Although no count of emergence was taken on 20 October 1991 (and only a non-robust estimate can be obtained from Figures A7a and A7b) a time by which most autumn cereals are sown, it can be seen from Table A5, in which the accumulated counts of emergence up to 21 September and 26 November are given, that it is possible for all populations, (apart from H2 and possibly H1 when buried) to have some seed left ungerminated by October 20th. It must be remembered that sufficient moisture was always available for germination to occur in all treatments. In years where little or no moisture is available, it is likely, particularly where seed is exposed to drying on the surface, that the percentages of seeds remaining ungerminated by 20 October would be greater than those given in Table A5.

There is a clear difference between the populations and species in the amount of seed that would be available to infest a crop at this latter date, with population C2 having the greatest amount and H2 the least amount available. Clearly, the late date of planting in the previous year (21 November 1990) may have meant late shedding in 1991. Nevertheless, the results of the populations grown for the laboratory tests, showed that there was a wide range in the shedding dates of populations. Thus, those populations which shed at a late date will be more likely to infest subsequent autumn sown crops because (a) there will be less time for them to have lost all dormancy, and (b) there will be less chance for moisture to be available to allow germination to occur.

The very dormant population C2 remained ungerminated both when buried and when exposed on the soil surface for a period of at least 43 days and then all of a sudden there was a very sharp increase in germination. This indicates that in this population there is a distinct environmental condition required for dormancy breakdown.

It can be concluded that:

- In one population of *B. commutatus* and two of *B. hordeaceus* ssp. *hordeaceus* investigated, the germination of surface-sown seed - i.e. in the light (even when supplied with adequate water for germination) was slower than that of buried seed (i.e. in the dark). The germination of one population of *B. commutatus* was not slowed by the presence of light.

- By 20 October, when most winter cereal crops would have been planted all populations of the species (apart from H2 and possibly H1 when buried immediately after shedding), would have had ungerminated seed available to infest an autumn-sown crop irrespective of whether the seed had been buried immediately after shedding or left on the soil surface.

- By 26 November, although germination had been slower, all seeds of each species and population had germinated on the soil surface, whereas when buried, small numbers of seed of population C1 and C2 were still viable and ungerminated. In the case of population C2 a few seeds were still viable and ungerminated by the following autumn, i.e. the seed can remain viable and dormant in the soil from one autumn cropping season to another.

- One population of *B. commutatus* was found which ended dormancy in autumn either in the dark or light very suddenly.

EXPERIMENT 2

An experiment to investigate the germination of two populations of *B. commutatus* and two populations of *B. hordeaceus* ssp. *hordeaceus* when either sown on the surface or buried at 2.5 cms in 1993.

Methods

Seed of two populations of *B. commutatus* (C1) and (C8) and two populations of *B. hordeaceus* ssp. *hordeaceus* (H11 and H14) were pot grown (Planting date was 28/29 September, 1992). The growing details are as for those used in the laboratory tests. The start of seed collection of each population was 30 July, 17 July, 2 July and 2 July respectively. Seed was collected over a period of a fortnight and planted approx. one week later. Sowing dates were August 24, August 12, July 23 and July 23 respectively. Between the start of collection and planting the seed was stored dry at ambient temperature but out of direct sunlight. Population C1B was a field collected sample from the same site at which population C1 was originally collected in 1990. Collection was made on 4 August 1993, and planting of this population made on 12 August 1993. The seed was stored between collection and planting in the same way as the other populations.

Two hundred "full" seeds (i.e. intact caryopses) of each population were separately planted in large square pots (27 cms x 42 cms), containing sandy, silty clay loam soil. The viability of each population was 100%. The seed was either planted on the surface or at a depth of 2.5 cms. There were four replicates arranged in a randomised block design. The seed was protected from large and small mammals, birds and slugs. All the seed was watered after it was sown and kept moist thereafter. On 24 December 1993, all the soil in each of the pots was separately wet sieved to recover any remaining ungerminated seed. The seed/soil residue was placed into trays to determine the number of viable seed, counts were made of any seedlings which emerged. Finally to stimulate all further viable seed to germinate each tray was treated with 400 ml of 1.0 g/l of gibberellic acid (GA_3) and any further emergence recorded. The percentage number of seeds remaining at 22 October and those remaining when the seeds were exhumed on 24 December were calculated and subjected to angular transformation to stabilise the variance, prior to analysis using an anovar.

Results

The germination/emergence up to the date of exhumation of each of the populations tested is given in Figure A8.

The populations were initially singled out for testing under field conditions from the 1992 laboratory tests, to give a dormant and non-dormant population of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus*.

The germination of the populations H14, H11, C1 and C8, behaved as predicted from the results of the laboratory tests carried out on these same populations in 1993, as light slowed

down germination. Population H14 proved to be very non-dormant, and both the buried and surface seeds had all germinated by 1 October. Population H11, which was originally selected for its higher dormancy, were more dormant, with an indication that the concerns, particularly of *B. hordeaceus* ssp. *hordeaceus* populations, that when some of these populations are set to germinate in the dark (i.e. buried) immediately after shedding, a fraction of the population remains ungerminated. This fraction represented 1.61% of the total number of seeds that germinated both by 22 October and 24 December (Table A6).

The selected less dormant population of *B. commutatus* (C8) showed that although almost total germination occurred in both light and dark, there was still a very small number of seed left in both the light (0.28%) and the dark (0.06%) (Table A6) by 22 October. With population C1 the level of germination in the light did not eventually overtake that in the dark before 22 October, as would have been predicted by the laboratory tests. However, the reason for this may be that the initial level of innate dormancy in this population in 1993 was relatively low, so the level of germination in the dark was higher than would have been expected (cf. in the 1993 lab. test of germination there was 95% germination in the dark after 10 day incubation). In addition the inhibition of germination by light in the field may be greater, because the light in the field was of higher intensity than that in the laboratory. So once a given level of germination is reached, further germination may be prevented by the high irradiance reaction of the phytochrome system.

Population C1B was field grown and collected at one date from the same original site as C1, but collected 3 years later. Germination of this population was inhibited by light to similar levels as C1 but the level of germination when buried was less than that in C1. This difference was thought to be due to the greater level of innate dormancy in C1B compared with C1. Again, some seed of population C1B was still ungerminated and viable in both the surface and buried treatments by 22 October. 22 October was selected as a target date at which to examine how many seeds were still left ungerminated, because by then most autumn cereal crops are sown, and the numbers of seed left ungerminated at this date would represent the potential numbers which could emerge in those sown crops.

It can be concluded that:

- In the presence of moisture, light slowed down the germination of seeds of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* when on the soil surface, compared with when they were buried.

- When moisture was present and when the seed was buried some seed (1.61% of total emergence) of one of the most dormant populations of *B. hordeaceus* ssp. *hordeaceus* (found in the laboratory tests) survived in an ungerminated condition until 22 October of the year of shedding. No seed of this population survived to the latter date when left on the surface.

- In the presence of moisture, when the seed was either buried or left on the surface, very few seed of a non-dormant population of *B. commutatus* seed survived ungerminated until 22 October of the year of shedding. In contrast, many more seed of a more dormant population of *B. commutatus* survived ungerminated by the latter date. When seeds of this population were collected from pot-grown plants, less seed survived ungerminated when buried until 22 October in the year of shedding, than when left on

the surface (1% compared with 9% respectively). However, more seed from a field collected sample from the same site of collection as the pot grown population survived ungerminated until 22 October, when buried, than when left of the soil surface (15% compared with 5%). The difference between the levels of germination in the buried seed was attributed to differences in innate dormancy.

- The experiment gives evidence that some populations, particularly those of *B. commutatus* have the ability to survive ungerminated, even when adequate moisture is available, from the time they shed until an autumn crop is sown (in the year of shedding), thereby allowing them to cause infestations in those crops.

EXPERIMENT 3

Experiment on the effect of different times of burial of *B. commutatus* seed on its long-term survival 1993.

Methods

A known dormant population (C1B) and a non-dormant (C8) that shed over approximately the same dates were selected for this experiment to avoid problems of differential after ripening (C1B field grown and collected August 4, C8 pot grown and collected 17-31 July). Details of pot growing were as previously described under laboratory tests in 1993. Batches of 3000 "full" seeds were weighed out separately of both populations. The exact number was subsequently determined by tests of the number of viable seeds per gram of seed. These tests showed 3089 and 3006 viable seeds of populations C1B and C8 respectively had been weighed out. The following treatments were set up for each population on 9 August 1993.

1. Seed left on the soil surface until 31 October 1993 - then all remaining viable seed recovered.

2. Seed left on the soil surface until 21 October 1993 - then buried at 12-14 cms until November 9 1994 when all remaining viable seed exhumed.

3. Seed left on the soil surface until 4 May 1994 - then buried at 12-14 cms until 9 November 1994 when all remaining viable seed exhumed.

4. Seed buried at 2.5 cms until 31 October 31 - then exhumed.

The treatments were designed to simulate various cultural practices which would result in the seed being buried at different times. Between collection and storage seed was stored dry at ambient temperatures but out of direct sunlight. The weighed batches of seed were separately sown either on the surface or buried (as per treatment list) in large rectangular pots 27 x 42 cms filled with sandy silty clay loam soil. After planting the soil was maintained in a moist condition until the autumn burial treatment (21 October 1993), thereafter the soil was subject to natural rainfall. Each treatment was replicated four times and the experiment laid out in a randomised block design. No seedlings were removed from

the pots but the seedlings were periodically cut down with shears to maintain their height at approx. 5 - 10 cms. The seed was protected from large and small mammals, birds and slugs.

When seed was recovered from "the surface only treatment" (treatment 1), as many seed as possible were first removed from the soil surface. The remaining process of seed recovery was then the same in this treatment as in all others. The entire contents of each pot was wet sieved, and the number of viable seeds remaining were determined as per the previous experiment (Expt. 2) in this section.

Results

The numbers of viable seed recovered from each treatment at their exhumation dates are given in Table A7.

The first treatment simulated a situation in which a farmer would leave the stubble uncultivated until just before sowing an autumn crop. This treatment contrasts with treatment 4, in which the seed was buried immediately after shedding (harvest). By exhuming the seed on 31 October 1993 (the shedding year) it was possible to determine the number of seeds that were still ungerminated and therefore a potential threat in an autumn-sown crop.

If a relatively non-dormant population such as (C8) was present, the immediate burial after harvest led to no seeds being present by the time an autumn crop would be sown. This would be expected, provided as in this experiment, adequate moisture was available. Whereas, when seed of this same population were left on the soil surface a small number of seed was still present. It appears therefore that by the time of planting an autumn cereal, viable seed would be still left on the surface waiting to infest the crop when cultivated into the soil. Clearly there is an inhibition of germination on the soil surface, and it could be expected that the HIR (high irradiance reaction) of the phytochrome system was responsible for this inhibition.

With the more dormant population of *B. commutatus* much larger numbers of seed were still present and ungerminated by 31 October, when buried or left on the surface compared with the less dormant population (C8). There was more seed of C1B remaining when buried (13.5%) compared with when left on the surface (8.8%) but this large difference was not significant, mainly due to the large variation between the replicates of buried seed.

Treatments 2 and 3 were designed to assess the long-term consequences of either ploughing down the seed or a dormant or non-dormant population in the autumn of the year of shedding or in the following spring, i.e. would there be an advantage in terms of numbers of seed lost from the soil by the next autumn if the stubble was left unploughed until the following spring, compared with being ploughed in the autumn of the year of shedding with relatively non-dormant populations (C8). There seems to be no difference between ploughing in the autumn or following spring, for no seed survived ungerminated until the next autumn using either method. Even with the more dormant population, there is very little difference between ploughing the seed down in the first autumn after shedding compared with the following spring (0.01% and 0.06% respectively survived until the second autumn after shedding) Table A7.

Discussion

If seeds are kept moist during the autumn:-

- Leaving relatively non-dormant populations of *B. commutatus* on the soil surface during the autumn will lead to a small amount of seed surviving ungerminated into the following autumn crop. Immediate shallow burial after shedding will not leave any ungerminated seed.

- With dormant populations of *B. commutatus*, irrespective of whether seed is shallowly buried or left on the soil surface, many seeds can be left ungerminated by the time a crop is sown in the autumn of the year of shedding. When buried immediately after shedding more ungerminated seed were found by 31 October (13.5%) compared with where seeds were left on the surface (8.8%) although this difference was not significant.

- In terms of the numbers of viable seed remaining ungerminated by the autumn of the year after shedding, with either a relatively non-dormant or a dormant population of *B. commutatus*, there was no advantage in leaving the burial of seed to plough depth until the spring after the year of shedding, compared with ploughing it down in the year of shedding. Only very few seeds of even the dormant population survived ungerminated until the following autumn whichever time of ploughing had been used (Autumn burial = 0.01%; Spring burial 0.06% of viable seed sown).

EXPERIMENT 4

An experiment to investigate the timing of autumn burial of seed of a *Bromus commutatus* (C1B) population with known on farm field persistence and persistence in the burial experiments of the present section (Expts. 2 and 3).

Introduction

In experiment 2 and 3 of this section, seeds of either *B. hordeaceus* ssp. *hordeaceus* or *B. commutatus* were either buried immediately after shedding, or left on the soil surface. There was evidence from these experiments that burial was aiding persistence compared with when seed was left on the soil surface. However, light was known to slow dormancy release (or germination), although complete germination of seed samples occurs in the light. In addition, higher temperatures reduce dormancy more quickly than lower ones. Higher temperatures would be present at the soil surface compared with under the soil surface. Putting all these facts together, it was decided to investigate exposing the seed on the soil surface for a given period, which should reduce dormancy and provide any light requirement (needed for germination) that the seed may have before burial in darkness. The latter reasoning provided the basis for experiments 4 and 5 in this section.

Methods

Seed of *Bromus commutatus* population CIB was collected from an infestation in winter wheat at ADAS Boxworth, Cambridge on 12 August 1994. Between collection and

sowing, the seed was kept at ambient temperatures but out of direct sunlight. On August 18 1994 batches of 3000 seed were weighed. At a later date, the actual number of viable seed per a given weight of seed were determined as previously described using laboratory tests. This enabled the actual number of viable seed planted to be calculated which was 2962 per pot = 26,121 per m^2). The seeds were separately sown on the surface of large square pots, 27 cms x 42 cm x 30 cm deep containing a mixture of 3 parts loam, 1½ parts peat and 1½parts Cornish grit. The seed was either buried at 2.5 cms immediately (18 August 1994) or buried on 20 September 1994 (on surface 33 days), 11 October 1994 (on surface 54 days) or 1 November 1994 (on surface 75 days).

There were four replicates of each treatment, which were laid out in a randomised block design. The pots were not sunk into the ground as in previous experiments but were insulated around their sides using 5.0 cm thick polystyrene sheeting to prevent side heating effects. The seeds were protected from large and small mammals, birds, insects and slugs. When seeds were buried, the soil/seeds were watered and kept moist throughout the experiment. All surface seeds received natural rainfall. As it was a very wet autumn, surface seeds were rarely without sufficient moisture for germination Figure A9. The emerged seedlings/germinated seed, were not removed, but were periodically cut to maintain their height at 1.5 cms. At each burial date, any emerged seedlings were cut down to almost the soil surface, great care was taken not to damage any ungerminated seed on the soil surface during this procedure. A further 2.5 cms of soil was then added to each pot to bury the seed. On January 25 1995 all soil from each pot was wet sieved to recover any ungerminated seed. The residue of seed/soil was placed in trays, and the total number of viable seeds determined by recording emergence both before and after treatment with gibberellic acid as in experiment 2 of this section.

Results

No viable seed was recovered on 25 January 1995 from the treatments where seed was left on the soil surface for either 33, 54 or 75 days. In the treatment where seed was buried immediately at the start of the experiment 0.58% SE.0.23.3df (17.25 seeds per pot) of the total seed that germinated was still present by 25 January 1995. Of this percentage 0.14% germinated without the action of gibberellic acid and a further 0.44% germinated when the gibberellic acid was added, giving an indication that some of the seed was quite deeply dormant, and required the action of a germination stimulator before germination could occur.

Discussion

In a wet autumn burying seed of a population of *B. commutatus* (known to show some dormancy when germinated in the dark) immediately after shedding, prolongs the persistence of its viable seed in the soil compared with when seed is allowed to remain on the surface of the soil for a period (33 days was the shortest period tested) before burial.

EXPERIMENT 5

An experiment to investigate the timing of autumn seed burial of a population of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus* which have dormant seeds.

Methods

The populations of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus* which had the most dormant seed of any of the collections made of each of the respective species were selected for this experiment. The dormancy status of the population was based on the percentage germination given after 50 days incubation at 15°C in the dark (1993 laboratory tests).

Seed was grown in pots in the same way as described for the 1993 laboratory seed tests. The seed of the two populations was collected over almost the same time period (H8 = 20-27 July and C2 = 22-29 July 1994). In the very short time between collection and burial, the seed was stored at ambient temperatures but out of direct sunlight. One thousand 'full' seed (i.e. seed with fully developed intact caryopses) of population C2 or H4 (later corrected for viable seed which gave 995 viable seed for each population, equivalent to 5,169 viable seed per m^2) were sown on the surface of soil (3 parts loam, 1.5 parts peat, 1.5 parts Cornish grit) contained in freely draining plastic trays (35 cms x 55 cms x 7 cms deep). No fertiliser was added. The trays had previous been let into the soil in a field, so that the final surface of the soil in the trays (i.e. after seed burial) was level with the surrounding soil. The trays were laid out in a randomised block design. The seed was immediately protected against large and small mammals and birds. During the first fortnight there was a very small seed loss due to insects, and so the trays were protected against insects and slugs with methiocarb. The seed was either buried at the start of the experiment or at monthly intervals thereafter (29 July, 25 August, 23 September, or 20 October, 1994). At the 2nd, 3rd and 4th burial dates the "full" seed remaining on and just below the soil surface was removed, counted, replaced and covered with 2.5 cms of the original soil mix. At each burial date the buried seeds were watered and kept moist thereafter. This was done to standardise the soil moisture conditions at each date of burial. Thus, at each burial date the experiment became a germination test of the seed which had been previously on the surface. Seedlings were counted and removed at approximately 10 day intervals. On 10 January 1995, the soil from each of the trays was separately wet sieved and the number of viable ungerminated seed determined as previously described in experiment 2 of this section.

Results

The results of the emergence behaviour of each of the treatments and for each of the populations are presented in Figures A10a and A10b.

The emergence of the *B. hordeaceus* ssp. *hordeaceus* population H4, showed that this population was much less dormant than the population (C2) of *B. commutatus*. The emergence of population H4, when buried immediately after shedding occurred rapidly and was almost complete in 11 days after burial. However, it was the only burial treatment in which any viable seed of population H4 remained by 20 October 1994 (a date used throughout this report as a date by which the majority of autumn sown cereal crops are sown) or by the exhumation date, 10 January 10 1995, Table A8.

The emergence of all seed of population H4 buried at the second burial was complete by 46 days after the start of the experiment. Likewise, although the third and fourth burial dates were not buried until 56 and 83 days after the start of the experiment, less than 0.2% of

seed that finally germinated were available for burial at the third date and none at the fourth date (Figure A10a).

Undoubtedly, the almost continuous availability of sufficient moisture to allow germination on the soil surface (see Figure A9) was responsible for allowing germination to proceed so rapidly in seed left on the surface. Thus, almost no ungerminated seed was left for the 3rd and none for 4th burial treatments.

The population of *B. commutatus* emerged slowly for the first 30 days after burial, but then the rate of emergence increased, the overall pattern of emergence being in the form of a sigmoid curve. Emergence was much slower than in the population of *B. hordeaceus* ssp. *hordeaceus*, with 50% emergence being recorded in approx. 50 days compared with 5 days in *B. hordeaceus* ssp. *hordeaceus* (Figure A10a and A10b).

When the burial of the seed of population C2 was left until the 2nd date, seedling emergence occurred more rapidly than if the seed was buried immediately at the start of the experiment (50% in 10 days). However, emergence did not continue at a rapid rate and by the 20 October date, 4.6% of seed still remained ungerminated (Table A8).

Large scale germination of the third and fourth burial treatments of population C2 started to occur 46 days after the start of the experiment which was before the seed was buried in either of these treatments. This time interval was almost exactly the same as that found in experiment 1 of this section of the report in which seed of population C2 had also been left on the soil surface. Why the seed changed to a germinable condition at this stage is not certain. It could be explained by the availability of a large amount of moisture due to a period of rainy days (Figure A9) just prior to the increase in emergence. However, population H4, was successfully germinating on the soil surface in the period immediately preceding the large increase in germination of population C2, so it would seem unlikely that moisture at the soil surface was limiting germination. Nevertheless, moisture could still offer a convenient explanation if population C2 was only able to take up, or utilise water when available at higher levels than population H4. For when buried at the third date, the seed continued its rapid germination until germination of the whole population was almost complete. Whereas, the rate of germination of seed left on the soil surface until the fourth date of burial, declined, until it was buried. This again could be explained by more moisture being available to the buried seed (in the third burial date) compared with the seed left on the soil surface (for the fourth burial).

A more likely explanation could involve the after-ripening of the seed. For, up until 46 days after setting up there was a relatively slow rate of germination of the seed when either buried or on the surface. At this date any light requirement of the seed to break dormancy in all the seed may have been fulfilled and the seed could have been after-ripened by the accumulation of sufficient "degree days" to allow the seed to germinate. This would account for seed continuing to germinate up to almost the maximum possible in the third burial treatment after the seed had been buried. Nevertheless, light, could still to some extent inhibit the germination process, as seen in the seed left on the surface until the fourth burial date (Figure A10b). A full understanding of this event would need further experimentation.

The amount of seed of population C2 remaining by the 20 October date is given in Table A8, and it can be seen that there is a progressive decrease the longer the seed is left on the surface. The amount of seed left in the 4th burial treatment represents the seed which has not yet been buried and has been on the soil surface continuously since shedding, and it is almost equal to the amount of seed remaining when the seed was immediately buried after it was shed (1st burial date). Thus, if autumn crops are to be sown, the best way to minimise carry over of ungerminated seed of *B. commutatus*, is to allow the seeds to remain on the soil surface for as long as possible after shedding, but they should be buried sufficiently ahead of crop planting to allow germination and destruction of seedlings before the crop has to be sown. Even so, some ungerminated seed may persist, because as can be seen in Table A8, some ungerminated seeds were found in each of the burial treatments at the final date of exhumation (10 January 1995). However, there was an advantage in not burying the seed for 56 days after shedding, because when the seeds were buried at or after this date, considerably less (and very few) ungerminated seed were found on 10 January 1995, compared with where the seed had been buried earlier (Table A8).

Discussion

- The most dormant population of *B. hordeaceus* ssp. *hordeaceus* collected during the project proved to be less dormant than the most dormant population of *B. commutatus*.

- The number of ungerminated seed surviving until October 20 (a time by which the majority of autumn cereals are sown) of the most dormant population of both *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* in this project, were reduced to very low levels if the seed was allowed to remain on the surface of the soil for at least 27 and 56 days respectively and then buried in moist soil.

- Before a crop is sown in the autumn of the year of shedding, even when seed is left on the soil surface for the maximum possible time to allow seed germination and control through seedling destruction, with very dormant populations of *B. commutatus* some ungerminated seed will survive until a crop is sown and possibly even longer (as judged by some seed remaining ungerminated by January of the following year).

- There was no advantage in leaving the seed of a very dormant population of *B. commutatus* on the soil surface for longer than 56 days prior to burial, in an attempt to reduce the number of ungerminated seed surviving when buried, because about the same and very low numbers survived by January of the following year when buried at either 56 or 83 days after shedding.

GENERAL DISCUSSION AND CONCLUDING REMARKS OF THE OUTDOOR MINI-PLOT TESTS OF THE GERMINATION AND LOSS OF SEEDS OF *B. COMMUTATUS* AND *B. HORDEACEUS* SSP. *HORDEACEUS*.

There is little distinction between the emergence behaviours of populations of *B. hordeaceus* ssp. *hordeaceus* and *B. commutatus* except that the most dormant populations so far collected are those of *B. commutatus*. This does not rule out the possibility that there

may be populations of *B. hordeaceus* ssp. *hordeaceus* that have high dormancy levels. In almost all populations of both species light slowed down germination.

Nearly all populations tested in the present project, when either buried or left on the soil surface had decreased to low levels (0 to 2%) of ungerminated seed by October 20 provided there was sufficient moisture to allow germination. So, the earlier concerns of a number of populations not totally germinating in the dark were not of such significance in the field as originally thought. This latter date has been taken as a yardstick by which time most autumn cereal crops need to be sown, and it therefore represents the maximum time, that there is, to get rid of any potential weed seed burden before the autumn crop is sown.

Nevertheless, there are populations in which the level of ungerminated seed remaining by October 20 can be substantially higher. The maximum recorded that remained ungerminated, when the seed was buried immediately after shedding into moist soil was 15.1% and the maximum if the seed was left on the soil surface was 11.4% (when subject to natural rainfall 1994) (both figures for *B. commutatus*). With these populations it would seem best to allow them to remain on the soil surface for at least 27 days before burial. For, when this was done with a fairly dormant population of *B. commutatus*, no seed was recovered by October 20. With even more dormant populations (one in 20), although leaving the seed on the surface for 56 days before burial reduced the numbers by October 20 to 0.27%, in another experiment this population was found able to survive from one autumn to the next if buried immediately after shedding (0.16%). Survival until the following autumn, if buried at later dates was not tested, but some seed (0.08%), certainly survived until January 10 in the year after shedding, if the seed was buried 56 days after shedding.

In the first three experiments in this part of the project concerning survival and germination of seed on the soil surface or when buried, the soil was kept moist and in the fourth and fifth experiments (timing of burial) the soil was also kept moist after the seed was buried. This was done to standardise conditions at burial time in the fourth and fifth experiments, and to reduce differences between years in the first three experiments. However, we do not know what may have happened if the seed had been buried into dry soil. There are several factors to consider. When "stored" dry in the dark, prior to imbibition, (which is essentially what burial into dry soil would have afforded), and if the presence of a given level of the Pfr form of phytochrome is important in determining whether the seed germinates, then when the seed is kept "dry" in the dark, the level of Pfr would decline though thermal reversion to Pr. Thus, the seed may not subsequently germinate when imbibed. However, it is known from other experiments where a population of *B. hordeaceus* ssp. *hordeaceus* was stored dry indoors in diffused light at 20-23°C, that the dormancy declined by 10% in 9 days. Thus, dormancy declines fairly rapidly when the seed in stored dry and at warm temperatures, so a similar rate of reduction would probably occur if seed was buried in dry warm soil. The outcome of the dormancy level may therefore be dependent on the balance between the Pr effect increasing dormancy, and the temperature effect reducing it.

Further research is needed to understand this dry storage effect. Certainly in dry autumns, as has been found previously with *B. sterilis*, much more seed would be available to infest a crop sown in the autumn of the year of shedding, due to "enforcement of dormancy" due to lack of water for germination.

As seed persistence is enhanced when it is buried immediately after shedding compared with when seed is left on the surface for a period of time before burial, it poses the question of what may happen in a field with deep cracks in the soil. It could be envisaged that seed would fall down these cracks and be effectively "buried" in moist conditions immediately after shedding. In which case, a proportion of the seed, especially if it is from a high dormancy population, may persist to the same extent as that found in seed buried immediately after shedding in this project.

In this project, all the outdoor experiments concerned with seed germination/losses of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus*, were protected from large and small mammals, insects and slugs. In the natural situation the seed would be exposed to all these predators and it could therefore be expected, that the percentages given for seed survival would be somewhat lower than those given in this report. The protection was given, to reduce variability between treatments and to confine losses to the known variables of germination and loss of viability.

ADDITIONAL DATA FOR OBJECTIVE 4 - THE ONSET OF VIABILITY AND CHANGING SENSITIVITY TO GLYPHOSATE IN DEVELOPING SEEDS OF SEVERAL BROMUS SPECIES

Introduction

There is very little information for farmers faced with deciding on the timing of the control of *Bromus* species by cutting or herbicide treatment in set aside land, apart from that given for *B. sterilis* in the first project (Orson, 1997) for HGCA. The following experimentation extends the original research to include other important *Bromus* species.

EXPERIMENT 1

Objective

To determine the onset of viability in developing seeds of *B. commutatus*, *B. hordeaceus* ssp. *hordeaceus* and *B. sterilis*.

Methods

In autumn 1992 seed of representative populations of *B. commutatus* (pop. C1), *B. hordeaceus* ssp. *hordeaceus* (pop. H5), and *B. sterilis* (pop. B41) were sown in 23 cm diameter pots containing sandy silty clay loam soil mixed with 10% gravel to which was added 5 g/l of 'Osmocote long-term fertiliser'. One addition liquid fertiliser feed was given when the panicles emerged, to maintain optimum growth conditions. Each pot was automatically watered to maintain the plants at optimum water status. The plants were sprayed with fenpropimorph to control mildew up to the 5 leaf stage and thereafter with colloidal sulphur to avoid the use of systemic fungicides which could have affected seed formation/viability. Flowering heads were not sprayed. There were four replicates of 14 pots for each species. To provide a source of seed all of the same age, a loose coloured ring was attached to the stem just above the penultimate leaves on stems on which panicles

emerged from the top most sheath at the same time. Two hundred panicles were marked in this way in each replicate.

It was found, that anthesis, first occurred in the basal florets of the most terminal spikelets in the panicles. Since the marked panicles emerged synchronously it was decided that by using the basal florets of the terminal spikelets, this would provide a source of seed all at the same and known stage of development. When the panicles had emerged, their spikelet development was monitored each morning by removing the terminal spikelet from twelve marked panicles in each replicate. The basal florets were dissected out under a binocular microscope. Anthesis was defined as the stage at which dehiscence of anthers had occurred in 50% or more of the basal florets.

Basal seeds were harvested from the spikelets at various times after anthesis for each of the *Bromus* species as given in Table A9.

At each harvest date the most terminal four spikelets were removed from randomly selected marked panicles. Fifty spikelets were removed from each replicate. The basal seed was dissected from each spikelet, and the seeds tested for viability in the laboratory using a Petri dish germination test. The fifty seeds from each replicate of plants formed a replicate in the Petri dish test which was started on the day of seed collection. The seeds were placed in a 90 mm Petri dish on one Whatman GF/A glass fibre filter paper, with three Whatman No.1 filter papers underneath, which were moistened with 8 ml of gibberellic acid (GA_3) at 0.25 g/l. The addition of GA_3 to the medium was necessary to ensure that an accurate representation of the sample viability was obtained. GA_3 promotes total germination (including that of dormant seed) and therefore avoids under representation of viable seeds due to some being dormant. In addition GA_3 speeds up germination. This was desirable because seeds at an early stage of maturity tend to leak sugars and other compounds on to their surfaces and on to the germination substrate. In situations where GA_3 is not used to produce rapid germination, viable seed may be rendered unviable by microbial colonisation of these exudates, allowing a build-up of inoculum which in turn attacks the seeds rendering them non-viable. Bactericides and fungicides cannot be added to the germination substrate, because these can affect seed germination.

The dishes were incubated in the dark at 15°C. The seeds were assessed for germination at regular intervals, and germinated seeds were counted and removed from the dishes. Any seeds not germinating after 23 days were considered non-viable and were discarded. The germination assessments were carried out under a green "safe-light" consisting of one 20 watt fluorescent tube filtered through two layers of No.39 Primary Green Cinemoid (Rank Strand Electric, London UK) producing a photon fluence rate of 0.14 m mol m^{-2} S^{-1} at the seed surfaces. This was necessary to avoid exposure to light which may have enforced dormancy in *B. sterilis* or slowed germination in *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus*.

Results

The time of onset of viability in the seed in *B. commutatus*, *B. hordeaceus* ssp. *hordeaceus* and *B. sterilis* is given in Table A10.

Discussion

Caryopsis development after anthesis in all three species of *Bromus* tested was very rapid. The figures for the times to seed viability for each of the species probably represent the earliest dates that could occur in the field, because seeds were considered viable if they could germinate to give 1 mm of root or greater. It may have been that the very young seeds with very small reserves could not all have formed seedlings. Thus, the figures given represent the "worst scenario".

However, to prevent the return of viable seed to the soil, the seed heads should be cut off the plants by the earlier of the two dates given in Table A10 for each of the species. The clippings should then be removed immediately and destroyed to prevent further maturation to a point where the seed becomes viable. A safer and easier proposition, would be to cut the plants down as soon as the panicles are seen emerging beyond the flag leaf ligule. This stage is easy to observe and cutting at this stage would allow for variation in panicle development within a field and also reduce the likelihood of sufficient development occurring in cut panicles which might allow viable seed to be shed, thus making it unnecessary to cart the cut vegetation from the field.

EXPERIMENT 2. - DETERMINATION OF THE TIME BEYOND WHICH THE SEEDS OF SEVERAL BROMUS SPECIES CAN NO LONGER BE KILLED BY GLYPHOSATE.

Methods

The plants in this experiment were grown in the same way as in Experiment 1 of this section. Two rows of ten pots were arranged at sowing for each of the following species. *B. commutatus* (pop. C1), *B. diandrus* (pop. D1), *B. hordeaceus* ssp. *hordeaceus* (pop. H5), *B. secalinus* (pop. S1) and *B. sterilis* (pop. B41). Two replicates were created within each row of pots giving a total of four replicates of five pots per species. Twelve panicles were marked with coloured rings in each pot in the same way as in Experiment 1 of this section. The panicles were marked when the panicles had just started to emerge from their sheaths. Onset of anthesis was determined using the same method as in Experiment 1 of this section.

The following treatments were randomly allocated to the pots in each replicate:

1. Plants sprayed at full panicle emergence.
2. Plants sprayed when seeds were at the soft dough stage.
3. Plants sprayed when seeds were at the hard dough stage.
4. Plants sprayed when seed had just started to shed from some of the spikelets.
5. Plants not sprayed.

Definition of stages

- Panicle emergence was monitored on a daily basis. Full panicle emergence was defined as the time at which at least 50% of the marked panicles were fully emerged from the flag leaf ligule.

- Dough development was monitored at 3 day intervals by randomly selecting five marked panicles from each replicate. The soft dough stage was defined as being when the caryopsis was the full length of the palea and the endosperm was moist, disintegrating easily between thumb and forefinger to produce a smooth paste.

- The hard dough stage was defined as being when the endosperm could be divided by the thumbnail. Upon application of firm pressure between thumb and forefinger the endosperm could be separated into dry crumbs.

- Seed development to each of the dough stages was considered to have occurred when at least 50% of basal seeds in the five most terminal spikelets had reached the relevant stage of development.

- Seed shed was monitored at three day intervals. Seed was considered to be starting to shed when the seed started to shed from the most terminal five spikelets in at least 50% of marked panicles.

At the appropriate times defined, replicate pots were removed from the experimental pot layout and sprayed in an enclosed cabinet using a Cooper Pegler knapsack sprayer with an ICI Polijet nozzle. The sprayer delivered 2.6 litres per min. of 7.2 g/l glyphosate solution at a pressure of 2 bars (29 psi). The plants were sprayed to run off over their entire surface. They were then placed under an outdoor well ventilated transparent polythene tunnel shelter, to prevent rain removing the glyphosate before it could fully enter the plants. During this period the plants were kept watered at the soil surface. Two days later the foliage of the treated plants was washed with water to remove surface deposits of glyphosate. Washing was necessary to prevent contamination of untreated plants upon return of the treated plants to the experimental pot layout. It also insured consistency in the amount of glyphosate remaining on the plants after each date of application. i.e. timing of the first rainfall after application could have been different for the different application dates.

The marked panicles were removed from the sprayed plants immediately after plant death and desiccation. Unsprayed plants were allowed to senesce and desiccate prior to harvest of the marked panicles. All the seed samples were stored indoors at ambient temperatures out of direct sunlight for at least a week to allow all the seed to reach a similar moisture content (12-14%). The seeds were then removed from the spikelets and a random sample of 50 seeds obtained from each treatment in each replicate.

The seed was placed into 90 mm Petri dishes on top of one Whatman GF/A glass fibre filter paper with three Whatman No.2 filter papers underneath together with 8 ml of distilled water. The seeds were incubated in the dark at 15°C for 3 days. Each sample was then transferred under a green safelight into another Petri dish containing the same filter paper arrangement as before, but moistened with 8 ml of 0.5 g/l of gibberellic acid (GA_3). The dishes were incubated at 15°C in the dark, and germination assessed as in Experiment 1 of this section.

Results

The effect of glyphosate application at the various defined times of the maturation of the seeds is given in Table A11.

When glyphosate was applied to any of the *Bromus* species at either full head emergence or at the soft dough stage of development no viable seeds were produced. Application of the glyphosate at any stage later than the soft dough stage resulted in some seeds of all the species being viable. It will be noted that by using glyphosate the time at which intervention to control seed viability has to occur is later than if control is by cutting (Table A11).

The results of the viability given in this experiment are those from *in vitro* Petri dish tests. It should be remembered that under field conditions, the results may be somewhat different. Any damage to the seed caused by the herbicide may make seeds more "leaky" producing exudates at their surface. The vast array of micro-organisms in the soil may then utilise these exudates as substrates for growth and in turn invade and kill the seed. Poor seed development or residual herbicidal products in the seed may also limit seedling growth. The figures given for the viability in this experiment after the various dates of application of glyphosate therefore probably represent the greatest viability of seed that could be expected after application at the various times.

Discussion

The findings from this experiment indicate that viable seed of *B. commutatus*, *B. diandrus*, *B. hordeaceus* ssp. *hordeaceus*, *B. secalinus* and *B. sterilis* can be completely prevented by applying a solution of 7.2 g/l of glyphosate to "run-off" at or before the soft dough stage of seed development.

STATISTICAL ANALYSES OF THE EXPERIMENTS IN THIS REPORT

Where appropriate in the report, the data has been analysed using anovars. In some experiments the data was subjected to an angular transformation to stabilise the variance before analysis. Where transformation of the data was necessary, values of both the transformed and the back transformed data are given in the Tables. The standard errors together with their degrees of freedom are given in the appropriate Tables. Where the data has been transformed the SEs should only be used with transformed data.

ACKNOWLEDGEMENTS

P. Brain and R. Butler of the Biometrics Group at IACR-Long Ashton Research Station for help with the design and analysis of the experiments contained in this report. J. Manning and T. Eshetu, for practical assistance with this project, and to Ingrid Potyka for help with the data analysis and the preparation of the charts and histograms. In addition, D. Marris for his contribution to the research into the time to onset of viability and the changing sensitivity to glyphosate in developing seed of the various *Bromus* species. Thanks are given to the Biotechnology and Biological Sciences Research Council of the United Kingdom for the grant-aided support they give to IACR and thanks are also given to the Ministry of Agricultural Fisheries and Food for their support of research into the biology and agroecology of weeds at IACR.

Table A1. No. of ungerminated viable seed recovered from plough depth in autumn 1992 after burial either the previous autumn or spring.

			Population 41			Population 50		
			per pot	per m^2	%	per pot	per m^2	%
Autumn Burial	Straw	dry*	0.5	4.41	0.10	0.25	2.2	0.05
		wet	0	0	0	0	0	0
	No Straw	dry	0	0	0	0	0	0
		wet	0	0	0	0.25	2.2	0.05
Spring Burial	Straw	dry	0	0	0	0.25	2.2	0.05
		wet	0	0	0	0.25	2.2	0.05
	No Straw	dry	0	0	0	0.5	4.41	0.10
		wet	0	0	0	0.25	2.2	0.05

Dry* For population 41 = Dry between setting up (26 July) and 6 Sept. = 42 days
For population 50 = Dry between setting up (16 Aug.) and 4 Oct. = 49 days

Total number viable seed planted of Population 41 = 4376/m^2
Total number viable seed planted of Population 50 = 4398/m^2

Table A2. Overall summary of main effects in Table A1. No. of seeds per m^2 recovered in each of the main treatments.

Treatment	No. of Seed recovered per m^2
Dry	1.65
Wet	0.83
Population 41	0.55
Population 50	1.93
Straw	1.38
No straw	1.10
Spring burial	1.38
Autumn burial	1.10

Table A3. The number of viable ungerminated seed recovered from the soil in the late autumn of the year after the year of seed shed.

	Population 34		Population 41	
	No. per m^2	%	No. per m^2	%
Autumn burial	0.93	0.005	0.62	0.003
Spring burial	0.62	0.003	0.31	0.002

Table A4. Dates of flowering of the various populations of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus*, harvest years 1992, 1993 and 1994.

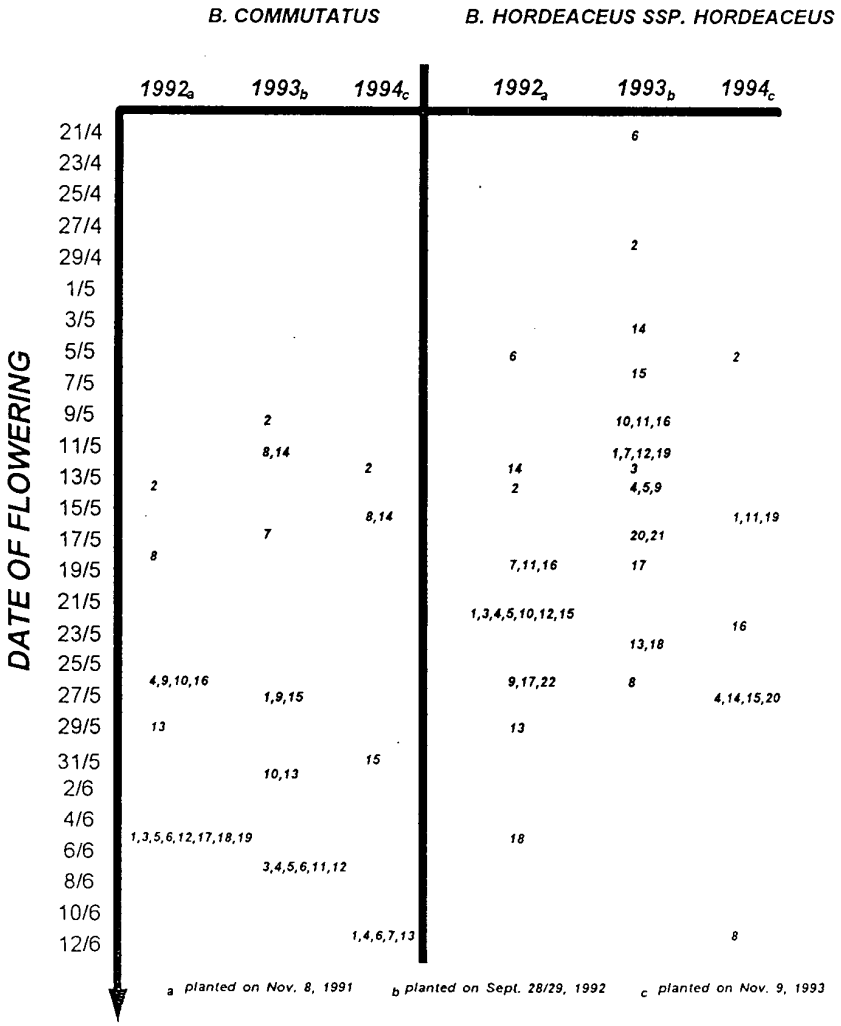


Table A5. The percent germination/emergence by 21 September and 26 November 1991 of populations H1, H2, C1 and C2 when they were either buried at 2.5 cms immediately after shedding or left on the surface between shedding and 26 November 1991 (Percentage of seeds germinated/ emerged based on final number germinated/emerged).

Population No	Buried at 2.5 cms		Surface	
	21 Sept	26 Nov	21 Sept	26 Nov
C1	92.0	99.8	18.8	100
C2	0	97.7	0.1	100
H1	97.7	100.0	84.5	100
H2	100.0	100.0	95.3	100

Table A6. Percentage of ungerminated viable seeds (angular transformed) of two populations of *B. commutatus* and two populations of *B. hordeaceus* ssp. *hordeaceus* at two dates in the autumn of the year of shedding (1993).

Population	Treatment	22 October		24 December	
H11	Surface	0	(0)	0	(0)
	Buried*	7.29	(1.61)	7.29	(1.61)
H14	Surface	0	(0)	0	(0)
	Buried	0	(0)	0	(0)
C8	Surface	3.06	(0.28)	3.06	(0.28)
	Buried	1.45	(0.06)	1.45	(0.06)
C1B	Surface	13.37	(5.35)	12.89	(4.98)
	Buried	22.87	(15.11)	21.85	(13.85)
C1	Surface	17.08	(8.62)	16.12	(7.71)
	Buried	5.45	(0.90)	4.40	(0.59)
	SED (df = 27)	1.83		1.96	

* buried at 2.5 cms
Back transformed data in parentheses. SED should only be used with transformed data.
LSD (P = 0.05) = SED x 2.05

Table A7. Number of viable seeds of each population (C1B, C8) remaining at the exhumation dates of each treatment.

Treatment	Mean number viable seed per pot				Percent of original number viable seed	
	C1B	SE (3 df)	C8	SE (3 df)	C1B	C8
1. Seed on surface until 31 October 1993	271.8	34.8	7.0	3.3	8.8	0.23
2. Seed on surface until 21 October 1993 then buried at 14 cm until 9 November 1994	0.25	0.25	0	0	0.01	0
3. Seed on surface until 4 May 1994 then buried at 14 cms until 9 November 1994	2.0	0.71	0	0	0.06	0
4. Seed buried at 2.5 cms until 31 Oct. 1993	415.5	140.4	0	0	13.5	0

Table A8. Number of viable seeds remaining ungerminated (based on the total number of seed which eventually germinated) a) at the last date of burial (20 October 1994) b) at the exhumation date (10 January 1995), for each of the burial dates and for each of the species.

	Burial Dates				
	29 July	25 Aug.	23 Sept.	20 Oct.	SED (9 df)
Julian days	0	27	56	83	
Population	Percentage remaining				
C2	13.95	4.59	0.27	11.44	4.06
H4	0.03	0	0	0	-
20 Oct.	Number remaining per m^2				
C2	624.7	210.4	13.0	520.8	-
H4	1.30	0	0	0	-
Population	Percentage remaining				
C2	1.71	1.58	0.08	0.11	0.60
H4	0.03	0	0	0	-
10 Jan.	Number remaining per m^2				
C2	74.0	72.7	3.90	5.19	-
H4	1.30	0	0	0	-

Table A9. Harvest times of basal seeds from spikelets in Experiment 1.

Species	Days after anthesis
B. commutatus	0, 3, 6, 9, 12, 14, 19, 22 and 46.
B. hordeaceus ssp. *hordeaceus*	0, 3, 6, 9, 12, 17, 22 and 44.
B. sterilis	0, 3, 6, 9, 12, 17, 22 and 44

Table A10. The onset of viability in three species of *Bromus* (test on freshly collected undried seed).

Species	Number of days post anthesis*	
	Viable seed not detected	Viable seed detected
B. commutatus	6	9
B. hordeaceus ssp. *hordeaceus*	9	12
B. sterilis	6	9

* Anthesis defined here as the time when 50% of the basal florets in the terminal spikelets of panicles have dehisced anthers.

Table A11. Percentage number of viable seeds produced on *Bromus* plants treated with glyphosate at 7.2 g/l to run off at various application timings.

Time of application	*B. sterilis*	*B. commutatus*	*B. hordeaceus* ssp. *hordeaceus*	*B. diandrus*	*B. secalinus*
Head emerged	0	0	0	0	0
Soft dough	0 (17)	0 (13)	0 (16)	0 (11)	0 (18)
Hard dough	100	97	3	91	75
Seed shedding	100	100	100	96	93
No application	100	100	100	100	100

Data in brackets = days after anthesis.

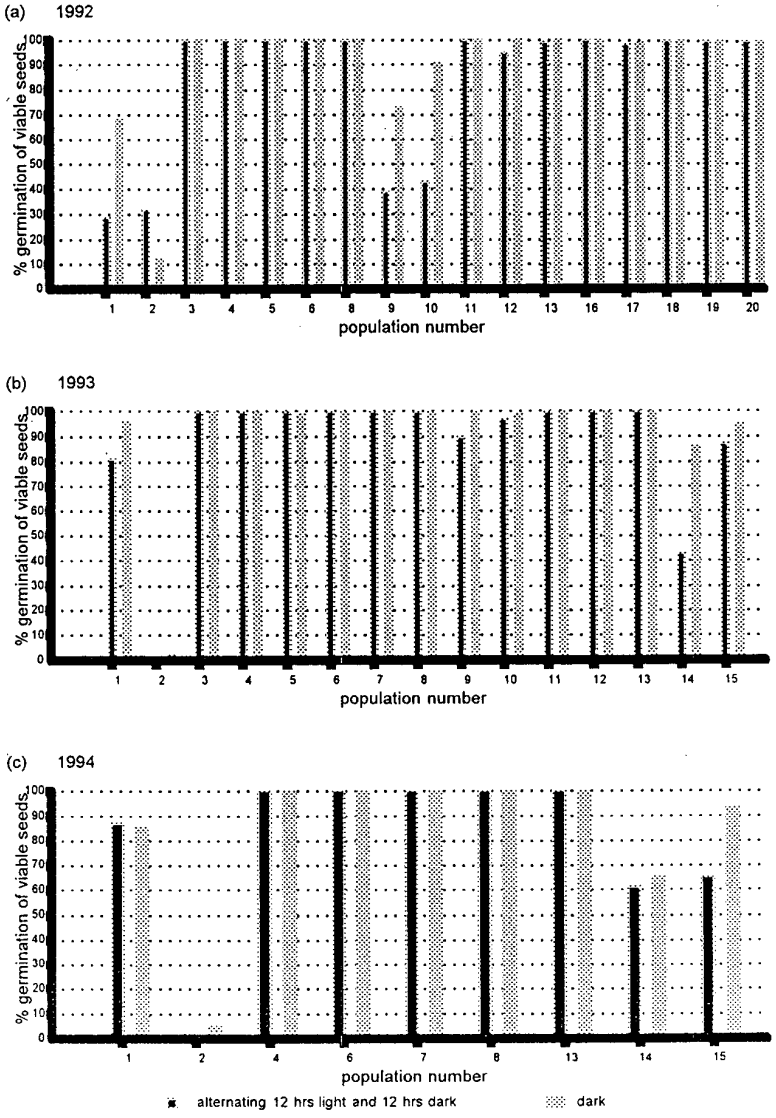


Figure A1. Percentage germination after 20 days, in two light regimes, of seed from various populations of *B. commutatus*, collected in 1992, 1993 and 1994.

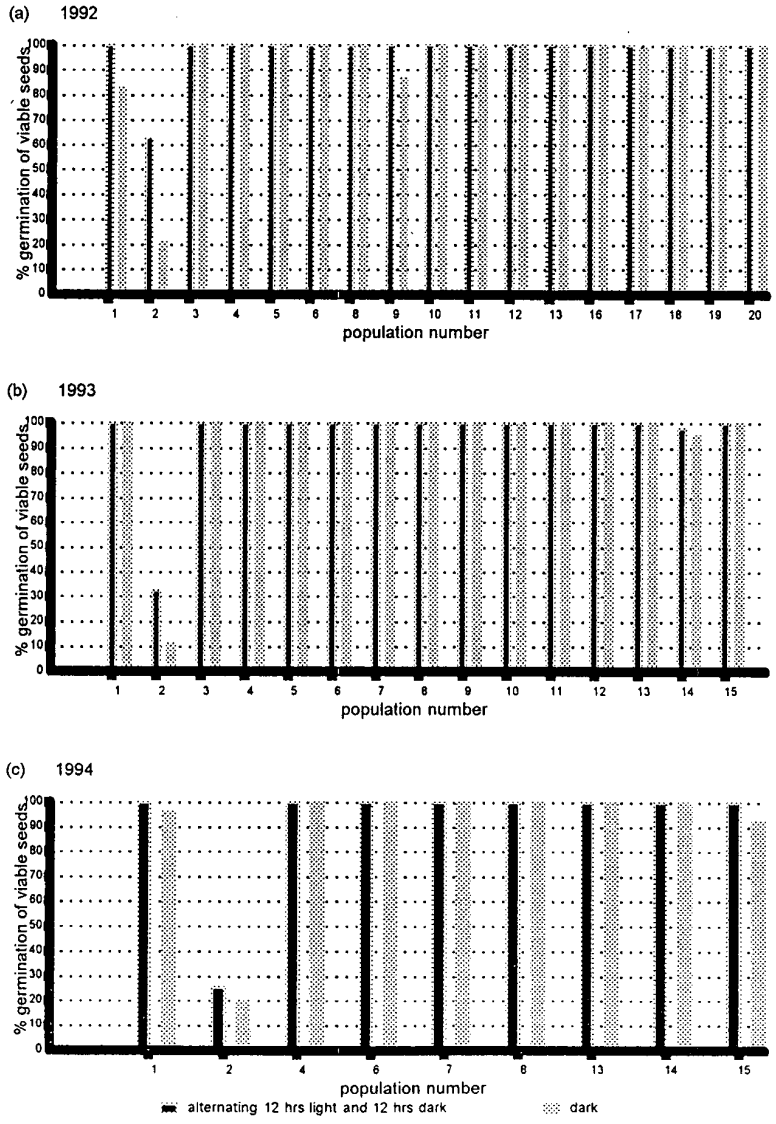


Figure A2. Percentage germination after 50 days, in two light regimes, of seed from various populations of *B. commutatus*, collected in 1992, 1993 and 1994.

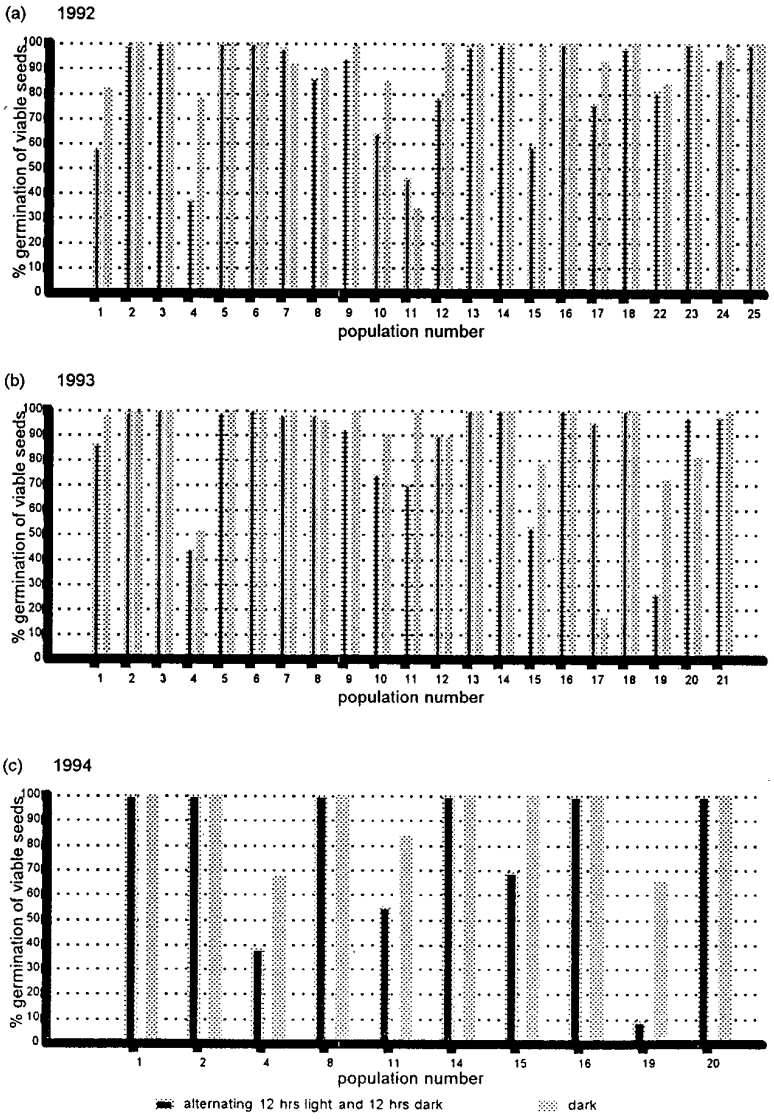


Figure A3. Percentage germination after 20 days, in two light regimes, of seed from various populations of *B. hordeaceus* ssp. *hordeaceus*, collected in 1992, 1993 and 1994.

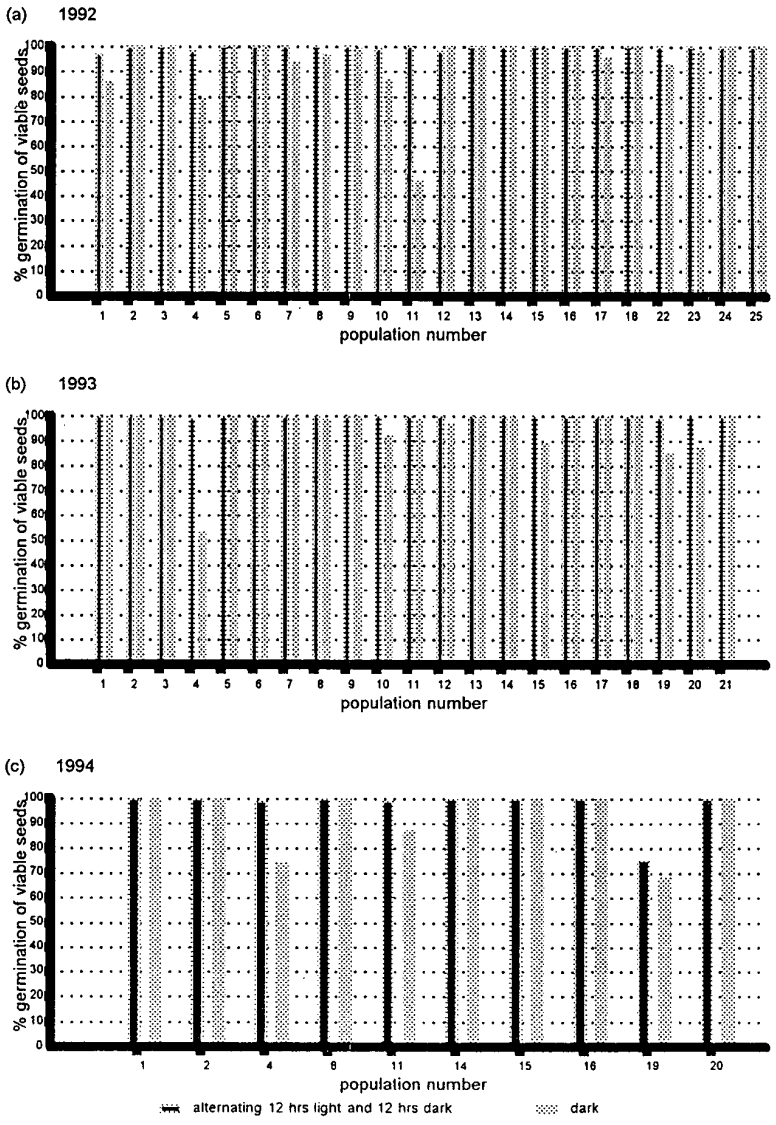


Figure A4. Percentage germination after 50 days, in two light regimes, of seed from various populations of *B. hordeaceus* ssp. *hordeaceus*, collected in 1992, 1993 and 1994.

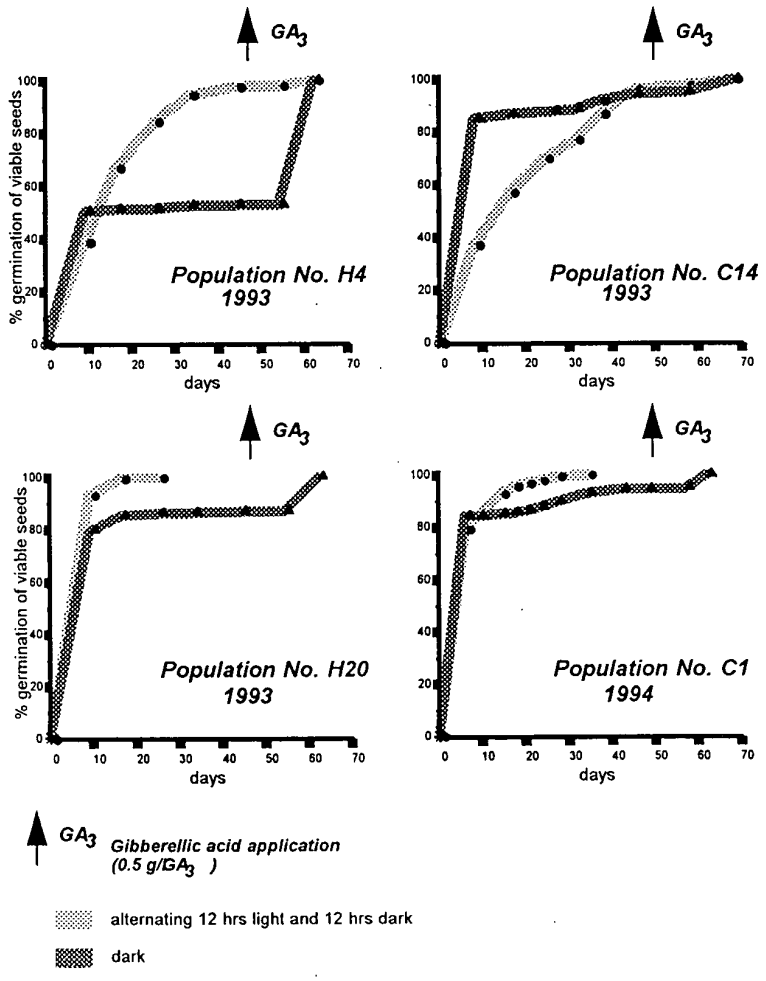


Figure A5. Germination in two light regimes of two populations each of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus*.

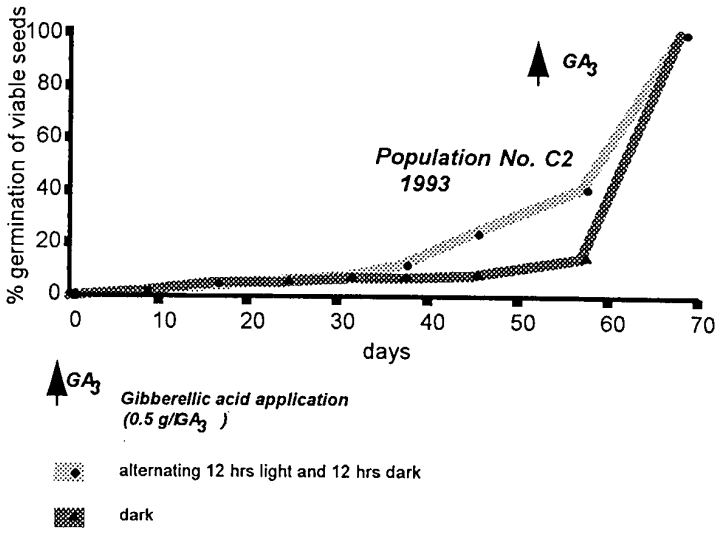


Figure A6. Germination of a highly dormant population of *B. commutatus* in both the light and the dark.

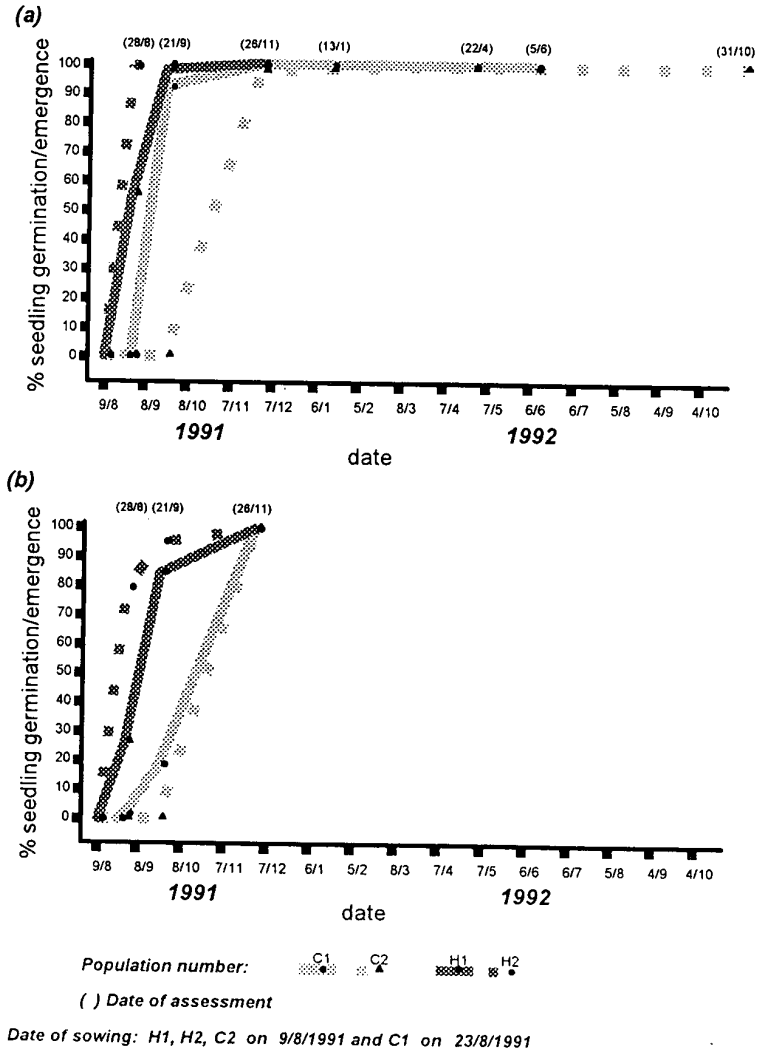


Figure A7. Emergence from 2.5 cms (a) and germination on the surface (b) of two populations of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus*.

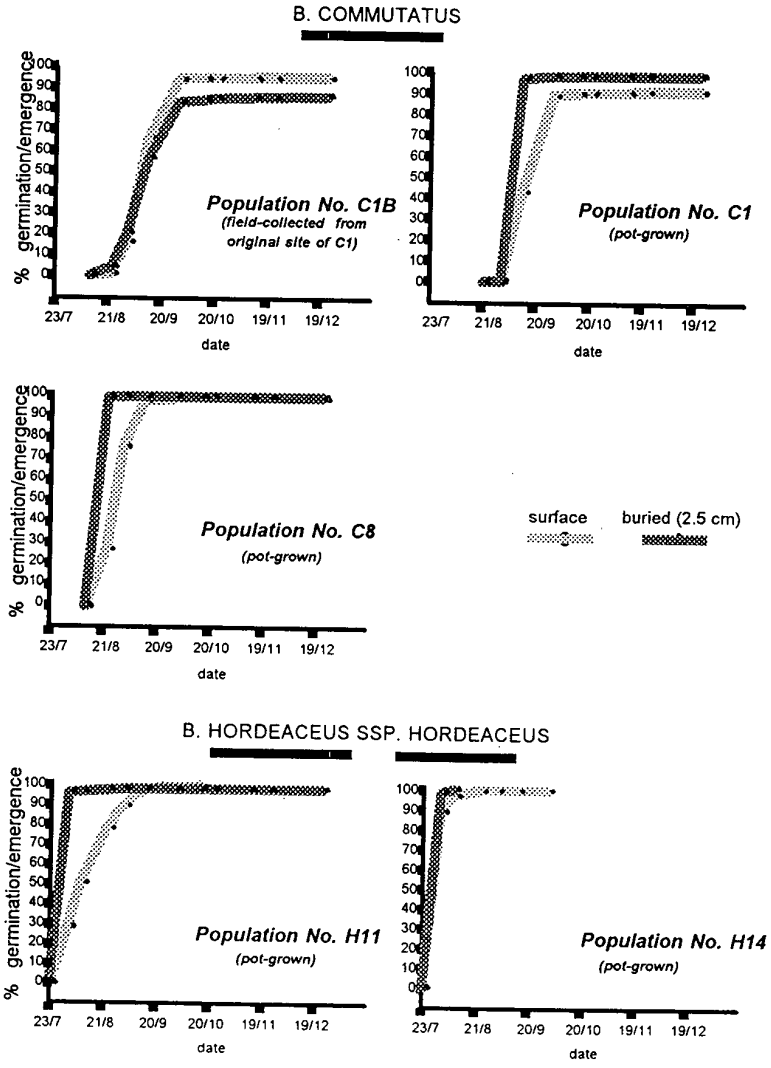


Figure A8. Germination/emergence of two populations each of *B. commutatus* and *B. hordeaceus* ssp. *hordeaceus*, either buried to 2.5 cms or planted on the surface.

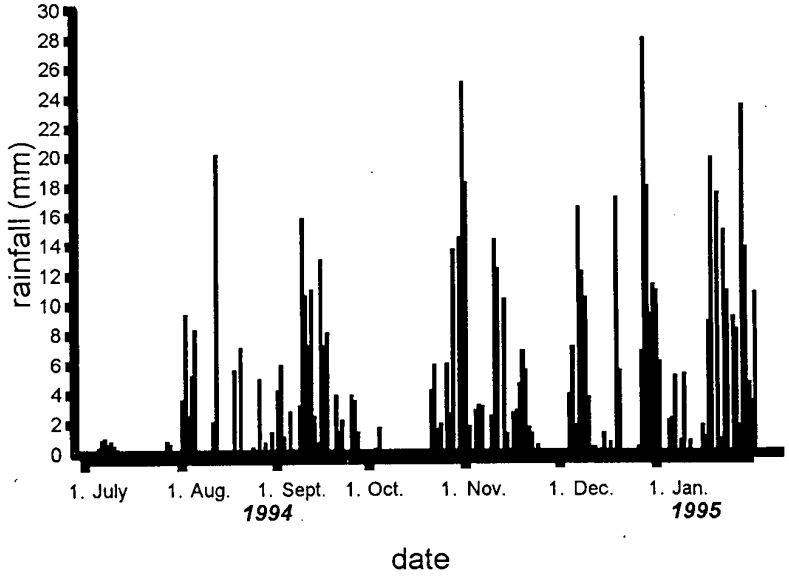


Figure A9. Rainfall at IACR Long Ashton from 1 July 1994 to end January 1995.

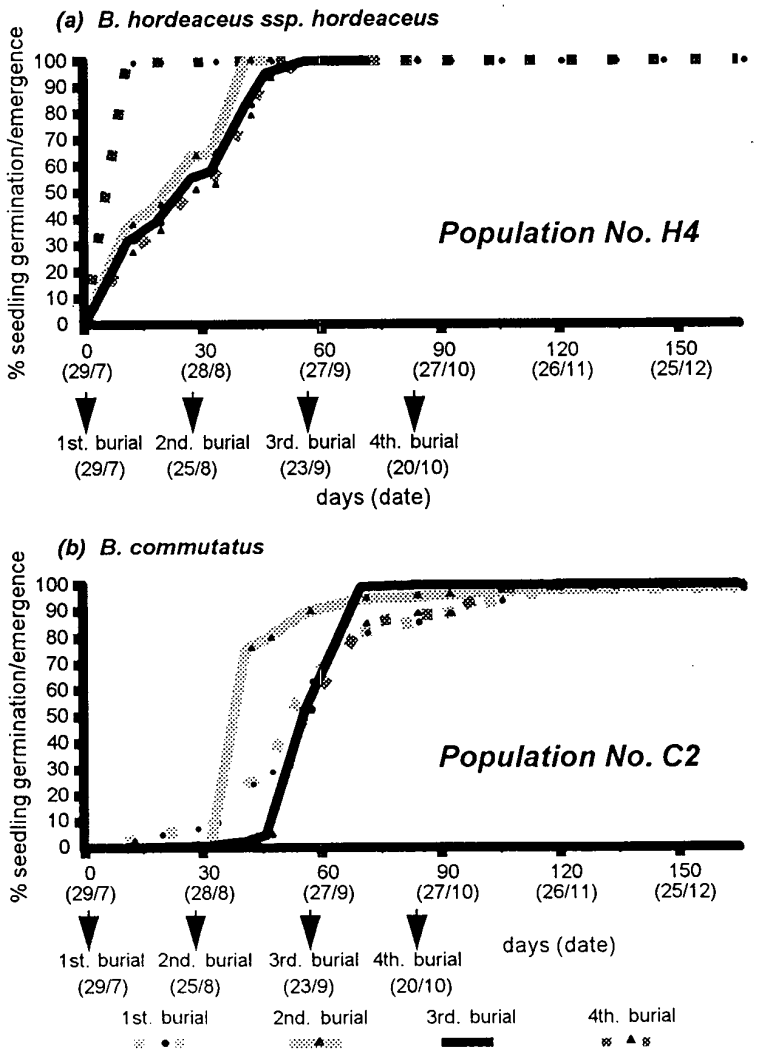


Figure A10. Germination/emergence of a population of *B. hordeaceus* ssp. *hordeaceus* (a) and of *B. commutatus* (b) at a range of burial dates.

PART B

DEFINING FACTORS WHICH AFFECT THE CULTURAL AND CHEMICAL CONTROL OF BROME SPECIES IN WINTER CEREALS

ABSTRACT

Tine or disc cultivation shortly after winter wheat harvest resulted in lower numbers of barren brome (*Bromus sterilis*) panicles in the following winter wheat crop when compared with cultivation four weeks later, provided the straw was removed at harvest. This was despite contrasting soil moisture conditions in the two autumns when the experimental treatments were applied. However, there was no advantage to early cultivation where the brome seed was covered by heavy residues of straw and chaff. The advantage of early cultivation in the absence of a straw mulch appeared to be more significant at the Boxworth site where the brome is known to a have some innate dormancy. The results between years suggest that the time from seed shed to harvest may be an important period in the population dynamics of the weed.

It was confirmed that ploughing resulted in significantly lower numbers of the weed in the following crop than from non-plough tillage. The timing of ploughing was not significant but the importance of effective burial of the seed to a depth from which it cannot emerge (Orson, 1997) was emphasised. Higher numbers of barren brome seeds produced plants in the following winter crop where effective inversion was not possible due to weather and soil conditions.

There was no consistent effect of soil consolidation following stubble cultivations in the autumn on barren brome populations in the following winter wheat. However, there was some suggestion that seed burial followed by consolidation close to the soil surface may be an efficient way to minimise populations in the following winter wheat crop.

Pot experiments in controlled environment and glasshouse experiments have suggested higher levels of control of barren brome when soil-applied herbicides, whose main entry to the plant is from the soil solution, were applied to a moist soil surface (Orson, 1997). This was confirmed in field trials in 1991/92, where higher levels of control were achieved with isoproturon and cyanazine when they were applied to a moist rather than a dry soil surface. This has been attributed to herbicides being more strongly adsorbed by dry soil. In contrast tri-allate, which enters the plant in the vapour phase, was not affected by the moisture levels of the seedbed. However, it should be noted that the time of application was in October and it is not known if the same results would have been achieved with tri-allate under warmer conditions in September.

Field experiments in the following season indicated that as the number of brome plants increased the percentage reduction of panicles due to early applied herbicides decreased, particularly where there were warm autumn conditions. It is considered that this was due to strong recovery growth of survivors being able to compensate for

plant loss due to herbicides where high populations of untreated brome plants would have been severely limited in the production of panicles due to inter- and intra-specific competition.

The field trials in 1994, proved that field to field variation in the efficacy of herbicides to control barren brome can be due to the depth from which the weed emerges.

OBJECTIVES

1. To measure the effect of cultivation type and timing, weather conditions and straw disposal on the population of barren brome (*Bromus sterilis*) in a following winter wheat crop.

2. To measure the effect of soil consolidation, time of ploughing and straw disposal on the population of barren brome in a following winter wheat crop.

3. To measure the effect of soil surface moisture at the time of application on the chemical control of barren brome in winter wheat.

4. To measure the influence of barren brome plant density on the level of control of panicles achieved with tri-allate and isoproturon.

5. To measure the effect of depth of burial of barren brome seed on the efficacy of herbicides.

OBJECTIVE 1 - TO MEASURE THE EFFECT OF CULTIVATION TYPE AND TIMING, WEATHER CONDITIONS AND STRAW DISPOSAL ON THE POPULATION OF BARREN BROME (*BROMUS STERILIS*) IN A FOLLOWING WINTER WHEAT CROP.

Background

Barren brome seeds germinate more rapidly in the absence of light (Orson, 1997) and hence early cultivation after harvest will encourage seedling emergence. However, straw residues might provide an alternative means of preventing light reaching brome seed. In addition, the value of early cultivations in dry conditions after harvest was being questioned because barren brome seed may be enforced into dormancy.

Method

Barren brome seed was collected from a field infestation at ADAS Boxworth (silty clay loam - Hanslope series) and at ADAS Drayton (clay - Lawford/Drayton series) when ripe and spread onto sub-plots in a standing crop of winter wheat on land which was not contaminated with natural populations of grass weeds. A polythene cover was put down behind the combine cutter bar to collect the straw on the no straw cover plots (Table B1).

The experiment was a split plot design with four replicates with the main treatment being:

Four main plots:
a. cultivate within 1 week after harvest
b. plough within 1 week after harvest
c. cultivate in early October
d. plough in early October

Three sub-plots
1. full straw cover, simulating immediately behind a combine fitted with a straw chopper
2. partial straw cover, simulating the edge of the swath of a combine fitted with a straw chopper
3. no straw cover, simulating straw removal

The sub-plots were 1 square metre and seedling emergence was assessed before the seedlings were destroyed prior to drilling the succeeding wheat crop. The plots were managed according to normal practice for the host farms, except that no grass weed herbicides were applied.

In the wet autumn of 1992, non-selective herbicides were applied shortly before seedbed cultivations to ensure that the brome seedlings were killed prior to drilling.

Results

1991/92

The autumn was relatively dry, with the only significant rain falling towards the end of September. The seedling counts were done before the second cultivation date and therefore compares early cultivation to no cultivation.

The seedling assessment at Boxworth in 1991 was not subjected to statistical analysis due to the small number of 'treatments' (due to the late cultivations not being possible) and replicates. However, it is clear that ploughing reduced the number of seedlings and there appeared to be more seedlings in the early cultivated plots where the straw had been removed (Table B2).

There were no significant differences in panicle numbers in the following crop within the ploughed plots at Boxworth (Table B3) but where the land was cultivated late there were less panicles where there was a full straw cover. Early cultivations in the absence of straw cover encouraged seedling emergence prior to drilling the crop but this did not result in a dramatic reduction in panicle numbers in the crop, despite these seedlings being killed during seedbed cultivations.

Early cultivation did not increase the number of seedlings emerged before final seedbed cultivations at Drayton (Table B4). This may explain why there were similar numbers of panicles from both early and late cultivation the following June (Table B5).

Overall, ploughing reduced panicle production at Drayton when compared to non-plough tillage but there was no significant effect of the timing of either ploughing or

cultivation. In addition, there was no effect of straw residue on panicle numbers. The difference in the influence of straw and the benefit of early cultivations between sites may have been due to the seed at Boxworth usually having some level of innate dormancy. Hence there would be a particular advantage in producing conditions in which seeds were more likely to germinate early.

1992/93

The autumn was wet in 1992, in contrast to the dry autumn of the previous year. However, there was a similar trend in the results at Boxworth in the two years, despite the differences in weather conditions.

There appeared to be an advantage, in terms of encouraging seedling emergence, from not cultivating in the presence of a full straw cover but there was less of an advantage from cultivating in the absence of straw cover compared to the previous autumn (Table B6). This may be explained by the fact that there was sufficient time and moisture to encourage significant germination on the soil surface in the absence of straw at Boxworth in the autumn of 1992. However, the conditions for germination in a wet autumn appeared to be optimised under the straw mulch in the absence of early cultivation. Here, the seed was in the dark and had little problem in emerging through the thin layer of straw.

There were far higher panicle numbers in the following wheat crop after the wet autumn in 1992 than after the dry autumn in 1991. This was contrary to farm experience and may be explained by the fact that the seed was not placed in the previous crop in the autumn of 1992 until just before combining, whereas in the previous year it was placed in the crop several days before combining. The reason for the delay in placing the seed in the crop in 1992 was because that it was feared that it would germinate in the crop prior to harvest. The higher panicle numbers in 1993 suggested that there may be high losses of seed between shedding and harvest, even under dry conditions. This may be due to partial germination and death of the seed and predation.

However, despite higher numbers, there appeared to be no disadvantage in delaying cultivations in the presence of straw and early cultivation reduced numbers in the following crop in the absence of straw. The disadvantage to late ploughing in autumn 1992 resulted from poor inversion occurring in the very wet conditions. Unlike the previous year, it was less easy to relate trends in seedlings numbers before drilling (and subsequently destroyed) with final brome numbers. This may due to the late placement of seed in the crop suggesting that the fate of seed between shedding and harvest has a significant influence on the population dynamics of the weed or that the wet weather enforced some dormancy.

The seedling and panicle counts at Drayton (Tables B8 & B9) in 1992/93 show similar trends to those at Boxworth (Table B6 & B7). However, it must be noted that it was impossible to establish a crop at Drayton and hence the panicles counts in Table B9 are in the absence of crop competition.

OBJECTIVE 2 - TO MEASURE THE EFFECT OF SOIL CONSOLIDATION, TIME OF PLOUGHING AND STRAW DISPOSAL ON THE POPULATION OF BARREN BROME IN A FOLLOWING WINTER WHEAT CROP.

Method

Barren brome seed was collected from the host farms (Boxworth and Drayton) in July 1993 and stored in dry conditions out of direct sunlight. The experiment was set out in a randomised block design on land not contaminated with natural populations of grass weeds (Table B10). The main plots had different levels of soil consolidation and time of cultivations whilst the sub-plots had the presence and absence of straw. Prior to combining, one metre square sub-plots had the crop removed by hand and the area covered with a plastic sheet. After harvesting, straw from this area was discarded by lifting and removing the plastic sheeting and seed spread at a population of 5,000/m^2. On the other sub-plot, the seed was placed in the crop where it was to be covered by large amounts of straw and chaff immediately below the straw chopper.

Three levels of consolidation were imposed on the main plots.

The six main plots were:

a. Plough early, no consolidation
b. Plough early, low consolidation
c. Plough early, high consolidation
d. Plough late, no consolidation
e. Plough late, low consolidation
f. Plough late, high consolidation

The two sub-plots were:

1. No straw cover, simulating straw removed
2. Full straw cover, simulating behind the combine

The experiments were subjected to normal wheat husbandry for the site, but no grass weed herbicides were applied.

Results

The different cultivation treatments achieved differential levels of consolidation in the top 20 cm of the soil as measured by using a shear vane with 19 mm vanes (Table B11).

There was sufficient moisture in the surface layers of soil prior to the first time of ploughing for germination of the brome seed and there was rain at regular intervals through the autumn, but soil conditions were never excessively wet. Early ploughing resulted in more seedlings by mid-October than late ploughing, particularly in the presence of straw, which may have resulted in poorer inversion (Table B12). There were no differences in seedling numbers before drilling due to soil consolidation. There was a trend to less brome panicles in the following crop with no consolidation except where the straw was removed and the land was ploughed early. This may due to a combination of better inversion which buried a high proportion of the seed to a

depth from which it could not emerge and poor emergence from depth due to a finer soil surface (Cussans *et al.*, 1996). There were no statistically significant interactions.

There were no consistent trends in the experiment at Drayton (Table B13) with the exception that ploughing late tended to result in higher populations in the presence of straw, perhaps due to insufficient inversion.

OBJECTIVE 3 - TO MEASURE THE EFFECT OF SOIL SURFACE MOISTURE AT THE TIME OF APPLICATION ON THE CHEMICAL CONTROL OF BARREN BROME IN WINTER WHEAT.

Method

Barren brome (*Bromus sterilis*) seed was collected from Boxworth in July 1991 and drilled at a rate 82 seeds/m^2 at Boxworth and 100 seeds/m^2 at two sites (Boghall and Bush) in Scotland in the autumn (Table B14). Herbicide treatments (Tables B15 & B16) were applied at three or four stages of brome development, and when required 5 mm of rain equivalent was applied to specified plots prior to spraying to provide a contrast between a wet and a dry soil surface. Herbicides were applied in a total volume of approx. 200 litres/ha.

Soil moisture was recorded at each time of application and measurements were taken of weed emergence and weed plants in the spring. Control was assessed as % reduction of panicle/m^2 in June 1992.

Results

Water applied to the seed bed prior to the pre-emergence timing increased panicle number, in the absence of herbicides, the following June at the Boxworth site (Table B15). A moist soil surface improved the control of the root uptake herbicides isoproturon and cyanazine but not tri-allate which is mainly taken into the germinating weed as a vapour. Despite the dry soil surface at the pre-emergence timing, the soil was moist at seed depth. Hence, weed emergence was not delayed. A fall in the efficacy of tri-allate could be envisaged if the soil was dry at seed depth, leading to delayed weed emergence.

The best control was achieved at the 2 leaf stage of the weed, where due to natural rainfall the soil surface remained moister for longer than a day after application and where there was further rainfall within a few days after application. The addition of 5 mm of water, either pre-emergence or at the 4 leaf stage of the weed kept the soil surface moist for less than 24 hours after application.

No drought periods occurred at the two Scottish sites (Table B16) and the site at Bush provided poor crop competition.

Tri-allate and the application of isoproturon at the two leaf stage of the weed gave reasonably effective control on all three sites.

OBJECTIVE 4 - TO MEASURE THE INFLUENCE OF BARREN BROME PLANT DENSITY ON THE LEVEL OF CONTROL OF PANICLES ACHIEVED WITH TRI-ALLATE AND ISOPROTURON.

Background

ADAS carried out an internal review of the results of experiments on the chemical control of barren brome in cereals. This between site review indicated that the percentage control of panicles with tri-allate was lower as barren brome population size increased.

Methods

A range of seed densities of the same stock of barren brome seeds (50, 75, 150, 300, 750, 1500 seeds/m^2) were broadcast in sub-plots on the cultivated soil surface prior to final seedbed cultivations on sites at Boxworth and in the Lothians in the autumn of 1992. Herbicides were applied on the main plots using a tractor mounted pneumatic granule applicator or sprayer. Sprays were applied in a total volume of 200-225 l/ha. The main plots were fully randomised in four blocks and the brome seed rates were randomised in each main plot (Table B17).

Results

Herbicide treatments significantly reduced brome panicles except at the two lowest seed densities (probably due to the relatively small differences in the numbers of panicles) and with tri-allate at the highest seed density at Boxworth. Isoproturon significantly reduced panicles compared to tri-allate at the two highest densities. These trends are demonstrated in the data on % reduction of panicles where particularly poor control was achieved by tri-allate at the two highest densities (Table B18).

Higher numbers of panicles occurred at the Boghall site, probably due to the low competition from the crop (Table B19). The number of brome panicles was lower in the isoproturon treated plots than the tri-allate treated plots at the highest population of brome. This again indicated that tri-allate provided inferior control to isoproturon at high brome populations, although the differences were not so apparent on Boghall site, where the autumn was exceptionally cold. The difference in the results between sites may be due to the timing or level of competition and recovery of brome surviving herbicide treatment.

The results suggested that surviving plants from an early herbicide application can recover strongly in the warm autumn conditions which occurred at Boxworth but not in the colder conditions which occurred at Boghall. Where brome densities were very high, the number of panicles/plant would be limited by intra- and inter-specific competition in a untreated crop. In such conditions the survivors of an early treatment are likely to numerous enough, in warm overwinter weather, to almost compensate for the loss of plants by producing sufficient panicles to almost fully exploit the resources of light, nutrients and moisture.

OBJECTIVE 5 - TO MEASURE THE EFFECT OF DEPTH OF BURIAL OF BARREN BROME SEED ON THE EFFICACY OF HERBICIDES.

Background

Higher levels of control of brome appear to be achieved in trials when the seed is sown close to the surface. This may be due to the close proximity of the crown roots of the weed to the soil surface. It is recognised that poor control of black-grass (*Alopecurus myosuroides*) with herbicides mainly taken up through the roots will occur when crown roots are not close to the soil surface. The depth of emergence may be a cause of variable control of brome between fields.

Methods

The same stock of barren brome seed was collected from Boxworth and sown at four depths at a density of 300/m^2 into 1m^2 sub-plots in October 1993 at Boxworth and Bush Estate. A crop of winter wheat was subsequently sown. The main plots were herbicide treatments which were randomised within 4 blocks and the depth of sowing of brome seed randomised within each main plot. Tri-allate granules were applied with a pneumatic granule applicator and the sprays with a commercial farm sprayer in a total volume of 200-225 l/ha. Panicles were assessed in the following summer (Table B20).

Results

During the two weeks after the pre-emergence application, 50 mm of rain fell on the site at Boxworth, which may explain the relatively poor performance of cyanazine and isoproturon (Table B21). These two herbicides are poorly adsorbed onto soil and may have become dispersed in the surface layers, reducing their efficacy whereas tri-allate is more strongly adsorbed. Establishment of brome was reduced by burial to 10-12 cm.

There was greater percentage reductions in brome panicles from the pre-emergence application of isoproturon when the seed was sown at less than 5 cm. The percentage reduction of panicles from isoproturon applied post-emergence and tri-allate was less from seed sown at the greatest depth (Table B22).

The most likely explanations for the poorer control of the deeply sown brome are that their crown roots may have been further away from the soil surface and/or that the production of crown roots was delayed. Isoproturon is taken up through the root system and the sooner the crown roots are formed after application and the nearer they are to the surface, the higher the uptake of the herbicide. This may explain why there was a greater effect from depth of sowing following the pre-emergence compared to the post-emergence application of isoproturon, where the herbicide would have longer to degrade prior to the establishment of crown roots from the more deeply sown brome. The probable reason for the reduced percentage control due to tri-allate at the deepest sowing was that the leaves may have emerged from the leaf sheath by the time

the emerging weed was approaching the soil surface. Tri-allate controls weeds through trapping the emerging leaves within a thickened leaf sheath.

There was significant emergence of brome from even the deepest sowing at the Bush Estate during a cold and wet autumn. Panicle numbers for each herbicide treatment was generally lower where the seed was spread on the surface compared to when it was sown at either 3 cm or 6 cm (Table B23). Tri-allate followed by isoproturon gave the most reliable weed control

Table B1. Treatment details - the effect of type and timing of autumn cultivations for barren brome control, in the presence and absence of straw cover

	Boxworth Harvest 1992	Boxworth Harvest 1993	Drayton Harvest 1992	Drayton Harvest 1993
Seed collected	29 July 1991	21 July 1992	2 Aug. 1991	19 July 1992
Seed spread	30 July 1991	4/5 Aug. 1992	2 Aug. 1991	18 Aug. 1992
No of seed/m^2	5,000	5,000	5,000	5,000
Date of combining	22 Aug. 1991	5 Aug. 1992	21 Aug. 1991	19 Aug. 1992
Early cultivation				
Method	Tine to 12cm.	Tine to 12cm.	Disc to 5cm.	Disc to 7.5cm.
Date	30 Aug. 1991	10 Aug. 1992	26 Aug. 1991	26 Aug. 1992
Soil condition	Dry	Moist	Dry	Wet
Early plough				
Method	20cm.	20cm.	20cm	20cm.
Date	30 Aug. 1991	10 Aug. 1992	26 Aug. 1991	26 Aug. 1992
Soil condition	Dry	Moist	Dry	Wet
Late cultivation				
Method	Tine to 12cm.	Tine to 12cm.	Disc to 15cm	Tine to 7.5cm.
Date	2 Oct. 1991	7 Oct. 1992	25 Sept. 1991	7 Oct. 1992
Soil condition	Dry	Wet	Dry	Very wet
Late plough				
Method	20cm.	20cm.	25cm	20cm.
Date	2 Oct. 1991	7 Oct. 1992	25 Sept. 1991	7 Oct. 1992
Soil condition	Dry	Wet	Dry	Very wet
Drilling date	11 Oct. 1991	14 Oct. 1992	4 Oct. 1991	-*
Brome seedling assessment	2 Oct. 1991	1 Oct. 1992	20 Sept. 1991	29 Sept. 1992
Brome panicle assessment	28 May 1992	7/8 June 1993	9/16 June 1992	11 June 1993

* - land was prepared for drilling 5 November but no crop was drilled due to very wet conditions.

Table B2. Brome seedlings/m^2 counted on 2 October 1991 - Boxworth

	Straw cover	
	Full	Nil
Cultivate early	463	950
Plough early	20	0
No cultivation	463	317

Table B3. Brome panicles/m^2 counted on 28 May 1992 - Boxworth

	Straw cover		
	Full	Partial	Nil
Cultivate early	250	272	236
Cultivate late	192	312	312
Plough early	48	35	24
Plough late	34	50	71

SED (24 df) 30.25 ($P<0.05$)
SED when comparing within the same cultivation 28.5

Table B4. Brome seedlings/m^2 counted on 20 September 1991 - Drayton

	Straw cover		
	Full	Partial	Nil
Cultivate early	0.0	1.0	1.0
Plough early	3.0	3.0	0.0
No cultivation	3.5	13.5	18.5

SED (24 df) horizontal = 12.12, vertical = 12.03

Table B5. Brome panicles/m^2 counted on 9/16 June 1992 - Drayton

	Straw cover		
	Full	Partial	Nil
Cultivate early	322	329	253
Cultivate late	398	361	302
Plough early	66	235	247
Plough late	131	98	41

SED (22f) horizontal = 68.8, vertical = 76.1 ($P<0.05$)

Table B6. Brome seedlings/m^2 counted on 1 October 1992 - Boxworth

	Straw cover	
	Full	Nil
Cultivate early	555	605
Plough early	95	90
No cultivation	855	504

Table B7. Brome panicles/m^2 (square root transformation) counted on 7/8 June 1993 - Boxworth

	Straw cover		
	Full	Partial	Nil
Cultivate early	780.3 (27.84)	849.0 (28.94)	940.8 (30.46)
Cultivate late	631.8 (24.86)	541.3 (23.13)	1473.3 (38.09)
Plough early	39.0 (4.77)	23.8 (4.81)	25.0 (3.94)
Plough late	247.3 (15.59)	256.5 (15.87)	696.8 (24.43)

SED (24 df) = (3.313) P<0.05

Table B8. Brome seedlings/m^2 counted on 29 September 1992 - Drayton

	Straw cover		
	Full	Partial	Nil
Cultivate early	131	164	217
Plough early	34	7	12
None	270	245	232

SED (24 df) horizontal = 64.4, vertical = 76.2 (P<005)

Table B9. Brome panicles/m^2 counted on 11 June 1993 - Drayton

	Straw cover		
	Full	Partial	Nil
Cultivate early	248	133	130
Cultivate late	156	290	359
Plough early	41	24	16
Plough late	14	29	41

SED (22 df) horizontal = 68.9, vertical = 67.7 (P<0.05)

Table B10. Treatment details - impact of soil consolidation on the emergence of barren brome

	Boxworth	Drayton
Seed collected	July 1993	July 1993
Seed placed in crop	25 August 1993	20 August 1993
Date of consolidation treatments:		
Early	25 August 1993	25 August 1993
Late	22 September 1993	16 September 1993
Consolidation treatments:		
No consolidation	plough	plough
Low consolidation	plough	plough
	power harrow	disc
High consolidation	plough	plough
	power harrow	disc
	roll	roll
Drill crop	23 October 1993	21 October 1993
Assessments:		
Brome seedling counts	21 September 1993	
Brome seedling counts	16 October 1993	
Soil consolidation	18 October 1993	20 October 1993
Brome head counts	1 July 1994	14 June 1994

Table B11. Soil shear strength (KPa) at Boxworth and Drayton

	Shear strength	
	Boxworth	Drayton
Plough early, no consolidation	10.4	20.1
Plough early, low consolidation	14.0	23.6
Plough early, high consolidation	13.9	24.5
Plough late, no consolidation	8.0	17.4
Plough late, low consolidation	14.3	24.1
Plough late, high consolidation	15.8	30.5
SED (18 df)	1.02	2.12

Table B12. Number of seedlings/m^2 on 16 October 1993 and panicles/m^2 on 1 July 1994 (square root transformed) - Boxworth

	Seedlings/m^2		Panicles/m^2	
	+ straw	- straw	+straw	- straw
Plough early, no consolidation	2.58	1.06	3.47	3.53
Plough early, low consolidation	2.04	1.43	4.17	1.14
Plough early, high consolidation	2.49	1.96	4.82	1.29
Plough late, no consolidation	0.00	2.08	1.45	3.88
Plough late, low consolidation	0.50	0.50	3.44	5.83
Plough late, high consolidation	0.50	0.25	2.54	7.26
SED (18 df)	0.667		1.033	

Table B13. Number of panicles/m^2 on 14 June 1994 - Drayton

	Panicles/m^2	
	+ straw	- straw
Plough early, no consolidation	6.3	13.5
Plough early, low consolidation	3.5	1.8
Plough early, high consolidation	5.3	4.0
Plough late, no consolidation	19.0	3.5
Plough late, low consolidation	27.0	6.5
Plough late, high consolidation	7.3	11.8

SED (18 df) horizontal = 7.11, vertical = 7.58

Table B14. Site details - the effect of the moisture status of the soil surface on the chemical control of barren brome with herbicides

	Boxworth	Boghall	Bush
Soil texture	silty clay loam	sandy loam	sandy loam
Drilling date			
Barren brome	9 Oct. 1991	18 Oct. 1991	11 Oct. 1991
Crop	11 Oct. 1991	18 Oct. 1991	11 Oct. 1991
Pre-emergence spray	15 Oct. 1991	21 Oct. 1991	11 Oct. 1991
First post-emergence			
Date	16 Jan. 1992	6 Feb. 1992	16 Dec. 1992
Brome growth stage	2 leaves	2 leaves	2 leaves
Second post-emergence			
Date	5 March	16 March 1992	25 Feb. 1992
Brome growth stage	4 leaves	4 leaves	4 leaves
Third post-emergence			
Date	-	7 April 1992	23 March
Brome growth stage	-	6 leaves	6 leaves
Assessment date	17 June 1992		

Table B15. Percentage reduction of brome panicles - Boxworth 1992

Herbicide	a.i./ha	GS of weed	Soil surface at the time of application		% control
			dry	moist	
isoproturon (IPU)	2.5 kg	Pre-em	✓		49.1
isoproturon	2.5 kg	Pre-em		✓	63.4
isoproturon	2.5 kg	2 leaves		✓	82.7
isoproturon	2.5 kg	4 leaves	✓		19.9
isoproturon	2.5 kg	4 leaves		✓	70.4
cyanazine	2.25 kg	Pre-em	✓		20.7
cyanazine	2.25 kg	Pre-em		✓	40.7
cyanazine	1.25 kg	2 leaves		✓	56.0
cyanazine+IPU	0.875 + 1.0 kg	Pre-em	✓		32.7
cyanazine+IPU	0.875 + 1.0 kg	Pre-em		✓	55.5
cyanazine+IPU	0.875 + 1.0 kg	2 leaves		✓	80.1
cyanazine+IPU	0.875 + 1.0 kg	4 leaves	✓		51.1
cyanazine+IPU	0.875 + 1.0 kg	4 leaves		✓	67.3
tri-allate granules	2.25 kg	Pre-em	✓		71.3
tri-allate granules	2.25 kg	Pre-em		✓	71.9
Untreated (/m^2)			✓		(26.6)
Untreated (/m^2)	water applied	Pre-em		✓	(39.1)
Untreated (/m^2)	water applied	4 leaves		✓	(25.7)

SED = 6.97 panicles/m^2

Table B16. Brome panicles/ m^2 at Boghall and Bush - June 1992

Herbicide	a.i./ha	Timing	Boghall	Bush
tri-allate	2.25 kg	Pre-em	4.0	9.3
isoproturon (IPU)	2.5 kg	Pre-em	14.3	46.0
cyanazine	1.75 kg	Pre-em	22.3	50.0
IPU + cyanazine	1.0 + 0.875	Pre-em	24.0	51.3
isoproturon (IPU)	2.5 kg	2 leaves	5.3	12.0
cyanazine	1.25 kg	2 leaves	13.3	32.5
IPU + cyanazine	1.0 + 0.875	2 leaves	8.3	31.5
isoproturon (IPU)	2.5 kg	4 leaves		17.3
IPU + cyanazine	1.0 + 0.875	4 leaves		37.3
isoproturon (IPU)	2.5 kg	6 leaves		35.8
IPU + cyanazine	1.0 + 0.875	6 leaves		34.3
Untreated 1			35.5	81.3
Untreated 2			34.0	87.5
SED			6.01	10.38

Table B17. Treatment details - the effect of barren brome population on the chemical control of panicles

	Boxworth	Boghall Farm
Soil texture	clay	sandy loam
Seed broadcast	12 September 1992	15 October 1992
Wheat crop drilled	13 October 1992	15 October 1992
Seedbed:		
Moisture	dry soil surface	dry soil surface
Quality	good	good
Tri-allate application	16 October 1992	16 October 1992
Isoproturon application:		
Date	18 January 1993	17 February 1993
Growth stage of weed	2-3 leaves	2 leaves
Panicle counts	18 June 1993	14 June 1993

Table B18. Panicles/m^2 (square root transformed) in June 1993 - Boxworth

Seed density /m^2	Untreated	tri-allate	isoproturon	% reduction	
		2.25 kg/ha	2.5 kg/ha	tri-allate	isoproturon
50	79.5 (8.85)	29.2 (5.21)	21.7 (4.59)	63%	73%
75	105.0 (10.22)	45.7 (6.54)	30.2 (5.43)	56%	71%
150	447.0 (20.86)	153.2 (11.88)	110.2 (9.98)	66%	75%
300	541.2 (23.11)	246.0 (15.01)	169.2 (12.55)	55%	69%
750	886.7 (29.32)	583.0 (23.57)	313.0 (17.46)	34%	65%
1500	1036.2 (31.65)	968.5 (30.73)	439.0 (20.49)	7%	58%

SED (45 df) = 2.824 and 2.070 within herbicide treatment

Table B19. Panicles/m^2 in June 1993 - Boghall Farm

Seed density /m^2	Untreated	tri-allate	isoproturon	% reduction	
		2.25 kg/ha	2.5 kg/ha	tri-allate	isoproturon
50	838	22	23	97%	97%
75	2063	65	19	97%	99%
150	2313	73	35	97%	98%
300	3813	130	81	97%	98%
750	4788	210	68	96%	99%
1500	6750	570	211	92%	97%

SED (45 df) = 112

Table B20. Site details - effect of seed depth on the chemical control of barren brome

	Boxworth	Bush Estate
Soil texture	Clay	Sandy Clay Loam
Brome sown	25/26 October 1993	
Crop sown	27 October 1993	
Pre-emergence application		
Date	2 November 1993	26 October 1993
Seed bed quality	Good	Good
Soil surface	Dry on top	Dry on top
Post-emergence application		
Date	2 February 1994	11 April 1994
Soil surface moisture	Moist	Moist
Growth stage of weed	1-3 leaves	Up to 2 leaves
Spring plant counts	21 March 1994	31 May 1994
Panicle counts	1 July 1994	23 June 1994

Table B21. Barren brome plants/m^2, March 1994 - Boxworth

	Timing	Dose a.i./ha	Depth of seed			
			Surface	2.5-3cm	5-6cm	10-12cm
Tri-allate Granules	Pre-em	2.25 kg	1.6	4.7	4.7	0.0
Isoproturon	Pre-em	2.5 kg	43.7	31.3	39.1	0.0
Cyanazine	Pre-em	2.25 kg	32.8	45.3	18.8	7.8
Isoproturon	1-3 lvs	2.5 kg	0.0	1.6	9.4	0.0
Tri-allate Gran +	Pre-em	2.25 kg +	0.0	0.0	1.6	0.0
Isoproturon	1-3 lvs	2.5 kg				
Untreated			50.0	26.6	39.1	3.1

SE (54 df) = 6.81 SE (within treatment) = 7.02

Table B22. Barren brome panicles /m^2 (square root transformed data), July 1994 - Boxworth

	Timing	Surface	2.5-3cm	5-6cm	10-12cm
Tri-allate Gran.	Pre-em	25.5 (4.85)	29.2 (5.14)	42.0 (6.43)	10.2 (2.75)
Isoproturon	Pre-em	108.7 (10.39)	87.2 (9.10)	155.8 (12.44)	10.8 (2.48)
Cyanazine	Pre-em	195.5 (13.96)	195.0 (13.94)	149.8 (12.10)	27.5 (4.98)
Isoproturon	1-3 lvs	9.3 (3.00)	34.7 (5.34)	43.0 (6.53)	4.7 (1.31)
Tri-allate Gran + Isoproturon	Pre-em 1-3 lvs	1.3 (0.93)	0.2 (0.25)	7.2 (2.58)	3.5 (1.32)
Untreated		181.8 (13.47)	167.3 (12.89)	150.0 (11.98)	12.3 (3.09)

Transformed SE (54 df) = 0.833
Transformed SE (within treatment) = 0.791

Table B23. Barren brome panicle/m^2, June 1994 - Bush Estate

	Timing	Dose a.i./ha	Depth of seed			
			Surface	3cm	6cm	12cm
Tri-allate Granules	Pre-em	2.25 kg	5.50	42.25	35.50	6.50
Isoproturon	Pre-em	2.5 kg	30.75	99.75	68.00	40.25
Cyanazine	Pre-em	1.75 kg	32.25	97.00	87.75	33.25
Isoproturon	1-3 lvs	2.1 kg	2.25	35.50	45.25	18.25
Tri-allate Gran + Isoproturon	Pre-em 1-3 lvs	2.25 kg + 2.1 kg	0.00	13.00	25.25	9.50
Untreated			14.15	57.5	52.35	21.55

SED (54 df) = 12.30

ADJUSTING PESTICIDE DOSE ACCORDING TO LEAF MOISTURE CONTENT OF THE TARGET

ABSTRACT

The moisture status of a weed at the time of treatment has a strong influence on the dose required of a foliage-applied herbicide with weeds being more susceptible as moisture content increases. The hypothesis tested by this project was that the measurement of moisture status or moisture stress of the weed would indicate herbicide susceptibility. A range of approaches was tested, including dialectrics, flourescence, porometry, infra-red gas analysis and use of a plant moisture vessel. These all indicated moisture status or moisture stress of the weed but had practical problems for their adoption as a field-based decision system. A major problem was that there were relatively small differences in moisture content between moisture stressed and unstressed plants.

Pot trials confirmed the importance of moisture status of the weed in determining the dose of a foliage-applied herbicide required for effective control. It is recommended that the approach is periodically reviewed to take into account new knowledge and new instrumentation which may help achieve the objective of matching herbicide dose to the prevailing weather conditions.

INTRODUCTION

The dose of pesticide is set by the manufacturer in order to ensure that the product works well under a range of circumstances. If the more favourable conditions for activity could be identified, lower than recommended doses could be used with confidence.

In the field it is well known that annual broad-leaved weed herbicides such as bromoxynil/ioxynil/mecoprop and mecoprop alone are less effective under dry conditions, particularly on mayweeds. Under controlled conditions Merritt (1984) demonstrated less ioxynil entry into dry-grown common chickweed compared to moist-grown plants. The efficacy of herbicides which are highly mobile within the plant, for example, fenoxaprop-ethyl on black-grass (*Alopecurus myosuroides*) and glyphosate on common couch (*Elymus repens*) depends upon moisture availability in the soil and atmosphere (humidity). The efficacy of systemic fungicides may be similarly affected.

The ability to easily measure leaf moisture using electronic instrumentation would be a significant step forward. Ideally, this should be able to be used by the spray operative just prior to applying the spray.

OBJECTIVES

1. To evaluate dialectric sensors and other instruments for the measurement of moisture content of a range of plant material.

2. To measure the effect of soil moisture deficit and aerial humidity on moisture content of plants.

3. To measure the effect of plant moisture content on herbicide and fungicide efficacy.

4. To identify the part of the plant where moisture content most accurately predicts pesticide performance.

5. To develop the use of dialectric sensors or other instruments as a guide to herbicide and fungicide dose and to identify situations where adjuvants may improve performance.

EVALUATION OF INSTRUMENTS TO MEASURE PLANT MOISTURE STRESS

a) Dialectric sensors

A dialectric meter was loaned by the Department of Plant Sciences at Cambridge University. The technique involves the use of low levels of microwave radiation to measure moisture content.

The meter had a 1 mm diameter probe which was held against the leaf lamina to make a measurement. The degree and uniformity of pressure against the leaf seemed likely to be critical with the distinct possibility of actually puncturing the leaf resulting in more moisture and wrong readings. The first attempt to overcome this was to fit the probe into a plastic peg such that the probe tip was held uniformly against the leaf. This system was further modified by the ADAS Unit at Silsoe so that the probe was held by suction against the leaf at a uniform pressure.

b) Fluorescence meter

The fluorescence meter gives a measure of damaged tissue. Only plants under extreme stress would be expected to show damage. The readings using this meter showed no difference between water stressed and non-stressed plants:

Unstressed	0.845
Moderately stressed	0.851
Stressed	0.851

c) Plant moisture vessel

The 'pressure bomb' measures moisture in the plant by exerting an external air pressure on a leaf and recording the pressure at which the sap is extruded from the petiole. Difficulty was experienced in getting an adequate seal around the petiole of oilseed rape and the moisture-stressed grasses tended to fracture at high pressures and before the sap was extruded. The scale differences between stressed and unstressed plants looked as if they would be quite large. The drawback to this method was the inability to seal the plant into the vessel and the instrument was laboratory based. Modifications were discussed with the manufacturers but these were not successful.

Unstressed	8.1
Stressed	>20 when leaf fractured

d) Infra-red gas analysis (IRGA)

IRGA measures gas exchange between the plant and the atmosphere. When plants are photosynthesising actively, they use CO_2. A stream of air is passed over a leaf enclosed in a leaf chamber and the concentration of CO_2 is measured before and after passing over the leaf. The concentration will be reduced if the plant is photosynthesising actively. Plants under stress do not photosynthesise actively and hence the concentration is unaffected.

The IRGA also measures stomatal conductance (the rate of air movement through the stomata) and these readings suggested that this would be a good indicator and that the porometer, which is designed to measure this, might be an appropriate instrument to try.

Unstressed	85
Moderately stressed	50
Unstressed	0

e) Porometer

Plants under moisture stress will tend to close their stomata. The porometer measures air flow through the stomata and therefore can be used to give a measure which will be related to the plant's moisture stress. This instrument is easy to use as long as the leaf chamber with which it is supplied can be clipped to the leaf satisfactorily. However the plant's metabolic rate changes quickly with the weather conditions and it can be difficult to obtain stable readings under rapidly changing light levels

MEASUREMENT OF PLANT MOISTURE STATUS/STRESS

Plants were grown in a netted tunnel and watered normally to keep them at approximately field capacity. When the plants had one leaf, water was gradually limited so that the plants were slowly stressed over a period of days. Where appropriate, leaf moisture was measured by drying the leaf in an oven set at 100°C for 24 hours.

a) Dialectric meter

There was no clear relationship between dialectric readings and moisture content determined by weight for four species (Table C1).

b) Porometer

There was a clear difference in porometer readings on the plants grown under different moisture regimes (Table C2) but also a considerable variation between plants and leaves. However, provided enough readings were taken it would be possible to differentiate between the fully, partially and non-stressed groups of plants.

HERBICIDE DOSE RESPONSES ON MOISTURE STRESSED PLANTS

Perennial rye-grass plants were grown in pots and subjected to different moisture stresses. Plants were treated with diclofop-methyl (Hoegrass) and stressed plants required a higher dose than unstressed plants to cause the same level of damage. A typical response is given in Figure C1, where doses as low as 0.375 l/ha were giving equivalent performance in moist conditions to that given by 1.5 l/ha under dry conditions.

Oilseed rape treated with mecoprop-P (Astix) also showed that as the dose was increased, there was less difference between moisture regimes (Figure C2).

These studies demonstrate that moisture stress does influence the response of plants to herbicides and that it is possible to classify plants according to stress using various instruments.

Table C1. Comparison of dialectric reading and % moisture by weight for four species.

Species	Meter mean			% moisture by wt.		
	Normal	Moderate	Dry	Normal	Moderate	Dry
Rape	43.7	38.4	41.6	91.3	90.8	87.7
Linseed	39.8	39.8	34.0	86.5	79.3	77.7
Brome	38.3	37.2	24.9	88.1	87.9	83.8
Barley	29.4	38.7	30.7	88.4	87.9	86.2

Table C2. Porometer readings on oilseed rape grown under different moisture stresses.

Stress level	Plant No.	Replicate leaf	Porometer readings		
			day 1	day 2	day 3
None	1	I	0.7	1.2	1.7
None	1	II	1.2	1.8	4.3
None	1	III	2.2	1.3	1.6
None	2	I	4.0	4.2	15.0
None	2	II	2.2	1.1	9.5
None	2	III	3.8	4.2	21.0
None	3	I	43.5	1.8	8.3
None	3	II	3.2	18.0	18.4
None	3	III	21.5	1.9	8.7
Moderate	1	I	10.5	9.5	15.7
Moderate	1	II	18.5	7.5	26.6
Moderate	1	III	45.0	30.0	23.0
Moderate	2	I	60.0	25.0	21.8
Moderate	2	II	19.5	10.5	9.3
Moderate	2	III	16.1	3.4	18.5
Moderate	3	I	36.0	29.4	52.0
Moderate	3	II	29.4	45.0	38.0
Moderate	3	III	37.0	20.5	56.0
High	1	I	68.0	51.5	54.0
High	1	II	67.0	33.5	51.0
High	1	III	60.0	22.5	44.5
High	2	I	50.0	57.0	33.0
High	2	II	67.0	29.7	35.0
High	2	III	60.0	36.5	36.0
High	3	I	39.0	48.5	28.0
High	3	II	48.5	47.0	41.0
High	3	III	57.0	30.5	38.0

Figure C1. Response (in pots) of stressed and unstressed rye-grass to diclofop-methyl (Hoegrass).

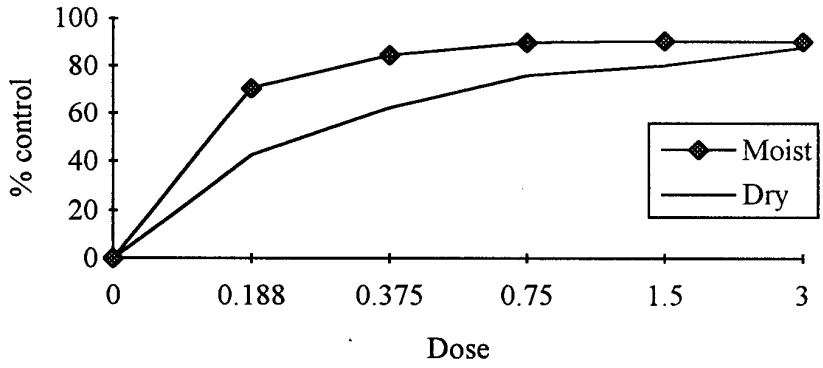
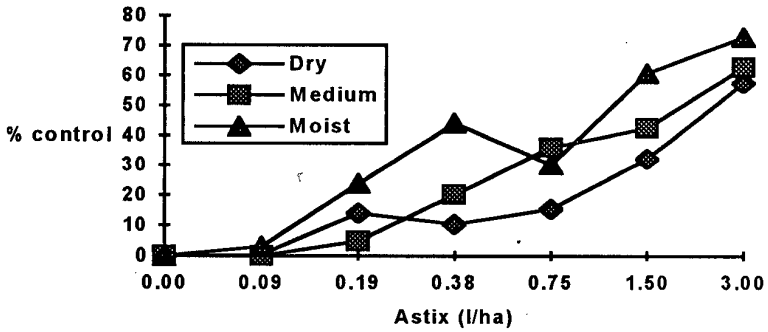


Figure C2. Response of oilseed rape grown under various moisture regimes to mecoprop-P (Astix)



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