HGCA

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THE DORMANCY AND CONTROL OF VOLUNTEER CEREALS AND *BROMUS* SPECIES IN CEREALS

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THE DORMANCY AND CONTROL OF VOLUNTEER CEREALS AND *BROMUS* SPECIES IN CEREALS

by

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This is the final report of a group of six projects co-ordinated by Mr. J. H. Orson, ADAS. The work started in 1988, lasted for four years, and was funded by the Home-Grown Cereals Authority. Grants provided were: Project 0085/4/87 – £40,003 to NIAB; Project 0086/2/87 – £19,415 to NIAB; Project 0091/2/87 – £32,750 to ADAS; Project 0092/1/87 – £10,904 to SAC-Edinburgh; Project 0093/3/87 – £52,320 to IACR-Long Ashton; Project 0094/2/87 – £26,070 to SCRI.

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ABSTRACT

This report records the findings of six co-ordinated projects on volunteer cereals and species of brome grasses as weeds of cereals. The work was initiated at a time when both were becoming increasingly important problems on UK farms. The need for research on brome had previously been highlighted in Project Report No. 17 - 'Seed dormancy and longevity in some brome species and cereals - a literature survey' by Dr Nick Peters, published by the Home-Grown Cereals Authority.

There were four principal objectives, which are listed below, together with the major findings which apply to each and the research organisation(s) involved.

1. To evaluate the effects of cultivations, depth of burial, straw disposal method and soil type on the long-term viability of brome grasses and volunteer cereals (ADAS, IACR, SAC, SCRI).

* Only a small proportion of seed of both barren and meadow brome emerged when the soil was ploughed to a depth of 15 to 20 cm (Parts C & D).

* A small proportion of both barren and meadow brome seed buried to a depth of 20 cm emerged (Parts C & D) but none emerged when buried to a depth of 25 cm (Part E). Emergence may be linked to soil texture, structure or consolidation.

* Ploughing more effectively reduced volunteer cereal emergence than tine cultivation. There was a reasonably close relationship between emergence of volunteers from specific depths and the depth of ploughing. This relationship did not exist with tine cultivation (Parts C, D & F).

* The difference between primary cultivations, in terms of volunteers from a specific crop, was highest in the following crop and diminished thereafter (Part B).

* A very small proportion of barley seedlings emerged from a depth of 20 cm and relatively few seeds survived more than one year in the soil. Dormancy of the seed stock did not influence long-term survival of the seed in the soil (Parts C, D & F).

* Strong competition from the cereal crop can reduce the number of fertile volunteer tillers (Part B).

* Burning straw and stubble was the most effective way to reduce volunteers, irrespective of subsequent cultivation (Part B).

2. To study the genetic variation in behaviour between ecotypes and influence of time of seed shedding on dormancy and pre- and post-harvest conditions on the induction and duration of dormancy in volunteer cereals and barren brome (IACR, SCRI).

* Large differences in enforced dormancy were found between populations of barren brome (Part E).

* Dormancy can be induced in some populations of barren brome. This research was the first to identify this aspect of seed survival (Part E).

* A very small proportion of barren and meadow brome seed can survive for longer than one year in the soil (Parts C, D & E).

* Vigour of seedling growth is critical to emergence of volunteer cereals in the autumn, particularly from depth, while retention of seed viability has a major effect on survival in soil over the winter and beyond. These two factors appear to be more important than post-harvest dormancy in determining levels of volunteer barley populations in cereal rotations (Part F).

* The emergence rates of cereals in pots from seed collected at harvest were very variable (Part F). 90% of barley seeds capable of producing seedlings in any

autumn did so within three weeks of sowing, unless delayed by lack of moisture (Part F).

* The penalties for inefficient burial of shed barley seeds may be consistently greater with some cultivars than others and in some seasons than others (Part F).

* The effect of either baling straw and removing it or straw chopping on the numbers of cereal volunteers is unclear (Parts B & D). Large amounts of straw may lead to more cereal volunteers in succeeding crops (Part B).

3. To conduct a survey of brome grass seed content and species and variety identity of wheat and barley sold in the market-place as grain (NIAB).

* Winter barley grain tended to be more contaminated by barren brome seed than the other major cereal crops. A survey of traded grain also indicated a tendency for more barren brome contamination of cereals grown from farmer saved seed (Part A)..

* A survey of traded grain indicated that mean contamination levels with other cereals are higher in winter barley than the other major cereal species (Part A).

* A survey of traded grain also showed that crops grown for livestock feed were more contaminated with other cereals than crops grown for the quality market (bread-making wheat or malting barley). Similarly the crops grown from farm-saved seed were more contaminated than crops grown from certified seed. Grain from crops grown after a two year non-cereal break and crops grown after plough tillage were, on average, less contaminated with other cereals (Part A).

* In a survey of fields in Scotland barley more often caused volunteers in a succeeding cereal crop than did wheat (Part E).

4. To investigate the relationship between standard laboratory dormancy tests and field germination in barley in relation to maturity and harvest (IACR, SCRI)

* An attempt was made to develop a test to identify at harvest crops in which post-harvest dormancy of cereal grains might encourage survival of viable grain and encourage volunteers in succeeding crops. All the tests evaluated considerably under-estimated the emergence characteristics of shed grain (Parts B & F).

The project work has challenged some of the previous findings on barren brome and explained why cultural control techniques have not proved totally effective. As a result cultural control guidelines have been modified. Farmers are advised to:

Seed quality and general management

* Ensure that cereal seed is free from barren brome seed, taking particular care with farm-saved seed.

* Minimise spread at harvest by not picking up brome from crop-side vegetation in the combine and ensuring that an significant area of weed-free crop is harvested last.

* Manage crop-side vegetation where barren brome is present by cutting before panicles emerge and repeat to prevent heading.

Primary cultivation

* Plough land (with good inversion) to a depth of at least 20 cm prior to winter cereals where the objective is to minimise barren brome in the subsequent crop. Annual ploughing and prevention of seed return (from the field or crop-side vegetation) should virtually eradicate the weed in two years.

* Where non-plough tillage is to be practised (only wise where brome populations are low and there are opportunities later in the rotation for effective control) cultivate

as soon as possible after harvest to cover the seed with soil (unless it is already covered with a layer of chopped straw).

* Where non-plough tillage is practised, delay drilling of an autumn-sown cereal for as long as is prudent and destroy emerged brome plants with a non-selective herbicide.

Chemical and cultural control

* Apply herbicides under optimal conditions for control.

* Barren brome is viable very shortly after anthesis and hence should be cut prior to heading in order to prevent the setting of viable seed.

* Headland infestations have been associated with the use of glyphosate on field margin vegetation allowing for the establishment of the weed which subsequently spreads to the crop margin vegetation and then to the crop.

* Adopt a rotation-wide approach. Use effective herbicides in broad-leaved crops to achieve very high levels of control.

* Check the dormancy of the population if problems continue despite following these guidelines.

The project work has clarified control guidelines for volunteer cereals. Farmers are advised to:

Seed quality and general management

* To be aware that wheat is less prone to cause volunteer problems than barley.

* Ensure that cereal seed is free from contamination with other cereals or other varieties of the same species. Particular care needs to be taken with farm-saved

seed. Winter barley is the most widely-grown cereal likely to be contaminated with volunteer cereals.

Primary cultivation

* Ploughing, to give inversion to a depth of at least 20 cm, gives more effective control than non-plough tillage, although control is not complete.

* Normally early disc or tine cultivation immediately after harvest will lead to lower volunteers in the following winter cereal crop, regardless of whether the land is ploughed on not-ploughed for succeeding autumn-sown crop . However, where the crop has matured under exceptionally cool conditions it may be best to delay this first tine or disc cultivation.

* In most years, the vast majority of shed seed capable of germination that autumn will produce seedlings within three weeks of incorporation into **moist** soil. Hence, with non-plough tillage, do not delay drilling beyond that point.

Chemical and cultural control

* A non-selective herbicide should be used to control seedling volunteers prior to the final seedbed cultivations.

* A small percentage of shed seed may remain viable in the soil for more than one year. Therefore, a rotational approach to cultivations may minimise the problem while allowing some non-plough tillage.

* A thick, vigorous crop will minimise the ability of volunteers to produce seed.

INTRODUCTION AND SUMMARY

BACKGROUND

The research on brome was preceded by a literature survey by Dr Nick Peters (HGCA Project Report No. 17 - Seed dormancy and longevity in some brome species and cereals - a literature survey). This concluded:

* That the initial research into the dormancy of barren brome largely ignored the possibility of induced dormancy. Induced dormancy is particularly important in the long-term survival of ungerminated seed in the soil.

* The review noted one case where seeds had persisted on the soil surface of uncropped land for more than one year. Very few experiments had been done on the survival of seed under field conditions.

* Little research had been done into the dormancy of different field populations of barren brome.

There was little knowledge concerning the seed biology of *Bromus hordeaceus* ssp. *hordeaceus* (soft brome), *Bromus commutatus* (meadow brome) and other *Bromus* species in the UK.

INCIDENCE

Barren brome and other brome species

Introduction

Barren or sterile brome (*Bromus sterilis*) and other brome species have been recurring problems in winter cereals since the mid-1970s. Barren brome was associated with the early drilling of winter cereals and other autumn-sown crops, particularly where non-ploughing methods of tillage were used. A survey funded by the British Crop Protection Council (BCPC) in 1989 indicated that brome grasses occurred as a weed in the field centres and headlands in 44% of crops in England and Wales (Cussans *et al*, 1992). The fact that only 12% of field centres had infestations of the weed under-estimates the problem because farmers, being aware of the risks from the weed, plough more regularly than is required for the control of other weeds and in some cases also delay drilling dates to minimise the risk from infestations likely to reduce yields. Control with herbicides is still very variable in cereals and generally unacceptable and farmers have had to rely on cultural control.

Research findings

* Winter barley grain tended to be more contaminated by barren brome seed than the other major cereal crops. This is due to the earlier harvest date, with barren brome shedding seed earlier than most grass weeds. There was a tendency for more barren brome contamination of cereals grown from farmer saved seed (Part A).

Volunteer cereals

Introduction

The problem of volunteer cereals in cereals has increased as a result of intensive winter cropping, the ban on burning cereal straw, earlier drilling of winter cereals, non-plough tillage and less straw burning. Volunteer cereals can have a large impact on both crop management and the quality of the harvested crop. Research Review No. 8, dormancy and longevity in self-sown wheat and barley (Pickett, 1988), identified weather conditions during the growing of a crop that would encourage greater dormancy of shed seed and noted that such seed could remain dormant in the soil for more than a year. Most of the recommendations for research made in the review were covered by the projects in this co-ordinated approach to the problem.

Research findings

* Mean contamination levels with other cereals were higher in winter barley than the other major cereal species. This may not only be a reflection of the number of volunteers in winter barley but also the early harvest in this crop is likely to take place before the volunteers shed. Another reason could also be that winter barley nearly always follows other cereals (Part A).

* Crops grown for livestock feed were more contaminated with other cereals than crops grown for the quality market (breadmaking wheat or malting barley). Similarly the crops grown from farm-saved seed were more contaminated than crops grown from certified seed. Grain from crops grown after a two year non-cereal break and crops grown after plough tillage were, on average, less contaminated with other cereals (Part A).

* In Scotland barley more often caused volunteers in a succeeding cereal crop than did wheat (Part E).

* The effect of the method of straw disposal (either bale/remove or chop) on the numbers of cereal volunteers is unclear (Parts B & D). Large amounts of straw may lead to more cereal volunteers in succeeding crops (Part B).

SEED DORMANCY AND GERMINATION

Barren brome and the other bromes

Introduction

Research at the Weed Research Organization (WRO) in the late 1970s and early 1980s was done on a limited number of populations of barren brome. The conclusions were that barren brome had little innate dormancy but dormancy could be enforced by dry conditions and/or high temperatures. Circumstantial evidence suggested that dormancy could be induced by light. It was also suggested from pot experiments that barren brome could not emerge from deeper than 12.5 cm. This was largely confirmed in one field experiment in a situation where effective burial of the seed was achieved by ploughing. It was also concluded that this weed was very competitive and could set a large number of viable seeds which were killed by straw burning.

Definitions

Innate dormancy - the state where a viable seed will not germinate even when all environmental factors are favourable for germination.

Induced dormancy - occurs if a seed that would normally germinate is placed in an environment which results in it no longer being able to germinate even when subsequently placed in conditions in which it would normally germinate.

Enforced dormancy - arises where a seed fails to germinate because the environment in which the seed would normally germinate is unavailable.

The Botanical Society of the British Isles describes the common name of *Bromus sterilis* as barren brome. It is commonly called sterile brome. All three names are used in this report.

Research findings

* Large differences in enforced dormancy were found between populations of barren brome (Part E). This aspect was largely ignored in previous research. Seasonal variations in dormancy were noted. Although this may not affect long-term survival of the seed it could be important for short-term survival, particularly for seed lying on the surface over winter where light enforces or induces.

* Dormancy can be induced in some populations of barren brome. This research was the first to identify this aspect of seed survival (Part E).

* A very small proportion of barren and meadow brome seed can survive for longer than one year in the soil (Parts C, D & E). In some circumstances those barren brome stocks with longer dormancy can persist longer but survival appears to depend on conditions of burial such as soil type and consolidation. Again, this was the first research to confirm observations made on commercial farms (Part D) and with traded grain (Part A).

Volunteer cereals

Pickett (1988) questioned the value of early stubble cultivations for the control of volunteers when the cereal crop had matured under cool conditions. Seed has a "ripening" requirement before germination can occur and this process more effectively takes place on the soil surface.

Research findings

* The 'ripening requirement' of seed was demonstrated after the wet, cool summer in 1985 in an experiment at Rothamsted where early cultivation increased volunteer barley, in the absence of straw burning, in a succeeding cereal crop compared to cultivation three weeks later (Part B).

* An attempt was made to develop a test to identify at harvest crops in which post-harvest dormancy might encourage survival of viable grain and encourage volunteers in succeeding crops. All the tests evaluated considerably under-estimated the emergence characteristics of shed grain (Parts B & F). Vigour of seedling growth is critical to emergence in the autumn, particularly from depth, while retention of seed viability has a major effect on survival in soil over the winter and beyond. These two factors appear to be more important than post-harvest dormancy in determining levels of volunteer barley populations in cereal rotations (Part F).

* The emergence rates of volunteer barley in pots from seed collected at harvest were very variable. This suggests that attempts to eliminate the potential volunteer barley seedbank by encouraging germination of seeds at or near the soil surface is unlikely to be completely successful, no matter how long an interval is available between annual crops. 90% of barley seeds capable of producing seedlings in any autumn did so within three weeks of sowing, unless delayed by lack of moisture (Part F).

* The penalties for inefficient burial of shed barley seeds may be consistently greater with some cultivars than others and in some seasons than others. Differences

between varieties in mean seed size at harvest did not influence emergence of seedlings from depth but in some varieties there was a link between speed of emergence from 3 cm and the ability to emerge from 11.5 cm (Part F).

PRIMARY CULTIVATION

Barren brome and other bromes

<u>Introduction</u>

Farmers who adopted cultural control measures, particularly ploughing, achieved less complete control than predicted from the original research into barren brome. The increased use of the plough throughout the 1980s and 1990s has helped keep the weed in manageable proportions on farms where effective inversion is possible. However, the ban on the burning of crop residues means that barren brome is a constant threat to successful winter cereal production. In addition, other *Bromus* species, notably meadow brome (*Bromus commutatus*), have become endemic on some farms, particularly in East Anglia. Meadow brome more difficult to control in cereals with selective herbicides in cereals and cultural measures than barren brome.

<u>Research findings</u>

* Only a small proportion of seed of both barren and meadow brome emerged when the soil was ploughed to a depth of 15 to 20 cm (Parts C & D). Previous results had suggested that ploughing would give more effective control than tine tillage but exaggerated the benefits of ploughing to a depth of 20 cm (Part A).

* A small proportion of seed buried to a depth of 20 cm emerged (Parts C & D) but none emerged when buried to a depth of 25 cm (Part E). Emergence may be linked to soil texture, structure or consolidation. This work contradicts earlier, more limited research findings, that barren brome could not emerge from depths greater than 12.5 cm.

Volunteer cereals

Introduction

The problem of volunteer cereals in cereals has increased as a result of intensive winter cropping, the ban on burning cereal straw, earlier drilling of winter cereals, non-plough tillage and less straw burning.

Research findings

* Ploughing more effectively reduced volunteer cereal emergence than tine cultivation. There was a reasonably close relationship between emergence of volunteers from specific depths and the depth of ploughing. This relationship did not exist with tine cultivation and by implication the burial of seed by tine cultivation is ineffective and not very dependent on the depth of operation (Parts C, D & F).

* The difference between primary cultivations, in terms of volunteers from a specific crop, was highest in the following crop and diminished thereafter (Part B).

* A very small proportion of barley seedlings emerged from a depth of 20 cm and relatively few seeds survived more than one year in the soil. Dormancy of the seed stock did not influence long-term survival of the seed in the soil (Parts C, D & F). Circumstantial evidence from Rothamsted suggested that ploughing each year may return a very small amount of viable seed to the surface which had been buried in previous years (Part B).

* Strong competition from the cereal crop can reduce the number of fertile volunteer tillers (Part B).

GUIDELINES FOR CONTROL

Barren brome and other bromes

Seed quality and general management

* Ensure that cereal seed is free from barren brome seed, taking particular care with farm-saved seed. Winter barley is harvested before most of the barren brome seed has shed and is more likely to be contaminated.

* Minimise spread at harvest by not picking up brome from crop-side vegetation in the combine and through combining two contaminated headlands successively (the contaminated headland last in one field and the contaminated headland first in the next field).

* Manage crop-side vegetation where barren brome is present by cutting before panicles emerge and repeat to prevent heading. Cutting should start in April. Keep vegetation short during late-spring and early summer to prevent nesting by birds. Do not destroy crop-side vegetation unless the land is to be managed in a way that prevents the establishment of barren brome.

Primary cultivation

* Plough contaminated land (with good inversion) to a depth of at least 20 cm prior to winter cereals where the objective is to minimise barren brome in the subsequent crop. Annual ploughing and prevention of seed return (from the field or crop-side vegetation) should virtually eradicate the weed in two years. Time of autumn ploughing is unlikely to affect populations in following crops but must be done in conditions for good inversion. Good consolidation may minimise the depth from which barren brome can emerge and the longevity of seed in the soil.

* Where non-plough tillage is to be practised (only wise where brome populations are low and there are opportunities later in the rotation for effective control) cultivate as soon as possible after harvest to cover the seed with soil and hence minimise light-enforced or induced dormancy. Recent HGCA-funded research has suggested

that a heavy straw cover may be more effective than early cultivation in reducing brome in a following winter cereal crop. However, the amount of straw cover has yet to be defined precisely.

* Where non-plough tillage is practised, delay drilling of an autumn-sown cereal for as long as is prudent and destroy emerged brome plants with a non-selective herbicide.

<u>Chemical and cultural control</u>

* Apply herbicides under optimal conditions for control. Recent HGCA-funded research suggests that tri-allate can be applied under when the soil surface is dry (but there is sufficient moisture at seed depth to encourage emergence) in mid-October and still achieve high levels of control of low populations. Higher populations are not well controlled. The manufacturers recommend that this herbicide is only used in sequences for the control of barren brome. Isoproturon should be applied when the soil surface is moist at any time from pre-emergence to the three-leaf stage of the weed. If the soil surface remains dry, delay to the four-leaf stage of the weed to achieve moist soil conditions. Cyanazine should also be applied to a moist soil surface; laboratory evidence indicates that rainfall shortly after application enhances control.

* Barren brome is viable very shortly after anthesis and hence should be cut prior to heading in order to prevent the setting of viable seed (Part E).

* Barren brome spread to new fields in Scotland was associated with an increase in winter cereals. Headland infestations were associated with the use of glyphosate on field margin vegetation allowing for the establishment of the weed which subsequently spreads to the cropped headland (Part D).

* Adopt a rotation-wide approach. Use effective herbicides in broad-leaved crops to achieve good control. Plough before a one year break of a broad-leaved crop and establish the subsequent winter cereal by non-plough tillage if complete control with herbicides has been achieved. The combination of two year burial and effective control in the break crop should provide good long-term control. However, this

may conflict with other objectives and barren brome control should not be considered in isolation (Parts C & E).

* Check the dormancy of the population if problems continue despite following these guidelines (Part E).

Volunteer cereals

Seed quality and general management

* Wheat is less prone to cause volunteer problems than barley (Part D)

* Ensure that cereal seed is free from contamination with other cereals or other varieties of the same species. Particular care needs to be taken with farm-saved seed. Winter barley is the most widely-grown cereal likely to be contaminated with volunteer cereals (Part A).

Primary cultivation

* Ploughing to a depth of at least 20 cm gives more effective control than non-plough tillage, although control is not complete (Parts B, C, D and F).

* High levels of volunteers can occur in the following winter cereal crop where non-plough primary tillage is being employed, particularly if sown early. Generally, early disc or tine cultivate after harvest to reduce volunteers in the following winter cereal crop rather than delaying for three weeks. However, where the crop has matured under exceptionally cool conditions it may be best to delay this first tine or disc cultivation (Part B).

* In most years, the vast majority of shed seed capable of germination that autumn will produce seedlings within three weeks of incorporation into moist soil. Hence, with non-plough tillage, do not delay drilling beyond that point (Part F).

Chemical and cultural control

* Use a non-selective herbicide to control seedling volunteers prior to the final seedbed cultivations (Part B).

* A small percentage of shed seed may remain viable in the soil for more than one year. Therefore, rotate cultivations to minimise the problem while allowing some non-plough tillage. For example, the cereal crop prior to a broad-leaved crop should be established after ploughing and the subsequent broad-leaved crop after non-plough tillage (where appropriate). Therefore, seed from the previous cereal will remain buried for at least two years while the seedlings can be effectively controlled in the broad-leaved crop (Parts B, C and F).

* A thick, vigorous crop will minimise the ability of volunteers to produce seed (Part B).

PART A

SURVEY OF THE QUALITY OF WHEAT AND BARLEY GROWN IN THE UK IN RESPECT OF STERILE BROME CONTENT, SPECIES PURITY, VARIETAL PURITY AND VARIETAL IDENTITY

M. Wray, NIAB

ABSTRACT

The objective of the three year grain survey was to analyse the species and varietal purity of samples of wheat and barley, and to identify factors associated with above average levels of varietal and other impurities by means of a questionnaire.

All samples were analysed for species purity. Varietal purity was assessed in the laboratory by means of morphological and chemotaxonomic tests. Control plots were also sown and recorded for varietal purity. Information from the accompanying questionnaire indicating intended market, seed source, husbandry techniques and methods of grain handling and storage was collated, combined with the sample results and statistically analysed to identify factors associated with above average levels of impurities.

The survey results show several key areas which may contribute to increased impurities. Samples from crops sown with farm-saved seed had higher levels of other cereal species and varietal impurities than samples from crops sown with certified seed. Where a previous cropping of two years cereals was used there were significantly higher levels of other cereal species, varietal impurities and non-cereals than in other cropping combinations. In samples where burning was used as the straw disposal method, cereal and varietal impurities were decreased but there were more weed seed contaminations. Of the non-burning methods, chopping and incorporating gave significantly lower weed seeds and fewer cereal and varietal impurities than baling. The cultivation method is also thought to be an important factor in sample purity. Since the start of the straw-burning ban from autumn 1992 these factors have been of particular interest.

INTRODUCTION

There is at present little information available about the quality of wheat and barley traded as grain in the UK. From the collation of information from samples submitted for testing at the Official Seed Testing Station (Tonkin, 1987) the results suggest that species purity is likely to be a matter of concern.

The aim of the three year grain survey which began in Autumn 1988 was to analyse samples of wheat and barley in respect of their species and varietal purity, and to identify factors associated with above average levels of impurities. This was carried out by laboratory and plot analysis and by the scrutiny of a questionnaire concerning factors associated with the growing of the grain.

METHODS

The main problem encountered was the collection of samples. The aim was to collect 500 samples each year from all over the country for analysis. However, in the first year only 289 samples were received. For the following two years, therefore, the assistance of a number of merchants was enlisted in order to obtain more samples. Despite these efforts and the invaluable help from the participating merchants still only 351 samples were received in year two and 331 in year three. Other problems included receiving samples without a questionnaire or questionnaires without samples, limiting the available data still further.

Varietal purity analysis involved examining morphological grain characters. The laboratory analysis of varietal purity in wheat is less discerning than barley as there are fewer characters can be used. A chemotaxonomic test using phenol solution was carried out on wheat samples and the degree of browning produced in the pericarp of the seed was visually assessed. Suspected varietal impurities were confirmed by an electrophoresis test. However, it is difficult to distinguish between varieties on the basis of this one character, and this often accounts for lower laboratory results than plot results.

Barley seed, was examined for several characters and the varietal purity of some varieties could be.determined on the basis of.just.one.character.

A field plot was sown for most samples where space was available. The plots were assessed several times once ear emergence had begun, and because of the many morphological characters available a more thorough assessment of varietal purity could be made. Spring barley plots, however, did not establish well, owing to the dry seasons, so the results should therefore be treated with extreme caution.

Species purity was assessed by a visual examination of 250g of the sample after mixing and dividing down. Separate assessments were made for sterile brome (*Bromus sterilis*), wild-oats (*Avena fatua* and *Avena ludoviciana*), common couch (*Elymus repens*) and black-grass (*Alopecurus myosuroides*). All other grass weeds were counted together and the total number of broad-leaved weeds and grass weed seeds were included in the 'total non-cereal' category. Impurities of other cereal species were counted separately.

Statistical analysis included calculating the mean and variance for each species purity category for each criteria listed in the questionnaire. The two-tailed unpaired t-test was applied to compare the means of each impurity category within each criteria of the questionnaire. However, it was often found that the variances were too large for differences to be statistically significant.

Because this was a survey and not a controlled experiment, any conclusions drawn from the results should be treated with caution.

RESULTS

Overall sample purity

The Table A1 gives the overall sample purity results including mean, minimum and maximum numbers of seeds in 250g over the three years of the study. The highest levels of contamination by other cereal species were found in the barley samples, as illustrated in Fig. A1. This could be attributed to the presence of wheat in the crop which would be less mature and therefore harvested with the barley. Barley contamination in wheat is less likely to be a problem since the barley would mature and shed before the wheat was harvested. Varietal impurities were higher in the barley samples than in the wheat in the laboratory due to the relative ease of detection. Results in the plots were similar for wheat and barley. Plot results for spring barley were adversely affected by poor establishment and laboratory findings are more reliable for this crop.

Non-cereal species contamination was relatively high in winter and spring barley and spring wheat with between 64 and 69 seeds/250g. Winter wheat had the lowest total non-cereal contamination with 25 seeds/250g. This may be attributed to a number of factors such as weed seeds being shed prior to the winter wheat harvest and the later drilling date of winter wheat than winter barley resulting in less autumn weed germination and higher levels of soil moisture enabling residual herbicides to work more effectively. The period of the survey coincided with generally low levels of rainfall which may have affected crop establishment and competition with weeds, particularly in spring cereals.

Common couch levels were the highest in spring barley with over 4 seeds/250g found on average compared to less than 1/250g in the other species. The worst black-grass contamination occurred in winter barley, and wild-oats appeared to be higher in spring-sown rather than winter-sown cereals. Sterile brome levels were generally quite low with mean levels across all cereals of 0.64 seeds/250g.

Analysis of intended use

Table A2 shows the mean levels of contamination of grain samples intended for the feed or quality market. As illustrated in Fig. A2 samples intended for a feed market had significantly higher numbers of other cereals (P=0.05) and varietal impurities (P=0.05) than those intended for a milling wheat or malting barley market. Feed samples also had higher levels of non-cereals including common couch and black-grass. This suggests that more care is taken over crops intended for 'quality' markets.

Effect of seed source

Samples from crops sown with certified seed generally had lower levels of other cereals and varietal impurities than those from farm-saved seed, as illustrated in Fig. A3. Although contaminations of some grass weeds were slightly higher for certified seed (Table A3), this probably came from the field and not from the original seed as guaranteed standards of purity apply to certified seed. In fact over the period of 1984-86, 90% of official samples of certified seed had no seeds of other species present in 125g, compared with only 33% of farm-saved seed samples with no contaminating species present (Tonkin, 1987). Further, over the period 1988-1990, an average of 83% of C2 samples had no contaminating cereal species present in 500g, and 93% had no species of non-cereals present (NIAB, 1992). Seed source, therefore, is a major contributory factor to the quality of the grain sample.

Analysis of the cleaning treatments of farm-saved seed

Analysis is difficult here because of a possible misinterpretation of the questionnaire. The number of responses to the relevant question was 167, but only 137 samples came from farm-saved seed (Table A4). Possibly the question was misread and some farmers answered it in respect of how they cleaned the grain after harvest, instead of before sowing. Nevertheless, not cleaning the seed resulted in a high value for total non-cereals of 218 seeds/250g, and other grass weeds of 69 seeds/250g compared with cleaning treatments, which is to be expected. Of the three cleaning treatments given, the mobile cleaner was the most popular but this had significantly higher levels of varietal impurities (P=0.05). The use of a static seed merchant's cleaner appeared to give the best overall results with significantly lower levels of other cereals (P=0.01) and sterile brome (P=0.05) than a pre-clean method, and lower varietal impurities than the mobile cleaner (P=0.05).

The effect of previous cropping

The number of possible cropping combinations for the previous two years could be enormous and so, was restricted in the survey to a few main groups; two years of cereals, either year as grass, either year as oilseed rape, two years of non-cereals or another combination. The data for previous cropping have been analysed by species to help explain the results (Tables A5 and Aa5). Many significant differences were found between the data which indicate how important this aspect is.

A previous cropping of two years of cereals was significantly worse for other cereals, total non-cereals, wild-oats, black-grass, other grass weeds and varietal impurities than most of the other cropping combinations, as shown in Fig. A4. In particular winter barley samples had a high level of other cereals present; an average of 30 other cereal seeds in 250g for this previous cropping. An explanation for higher levels of contamination in barley than in wheat has previously been advanced (Page 23 of this report). The level of other cereal contamination was also significantly higher when oilseed rape had been grown previously than after two years non-cereals. Varietal impurities were very significantly higher in the laboratory test (P=0.01) after cereals than after two years of non-cereals. This was confirmed in the plots particularly for wheat where impurities are detected more easily than by laboratory methods (Table Aa5). Continuous cereals was linked to increased amounts of grass weeds, particularly wild-oats, black-grass and common couch.

Where the previous cropping included one year of grass the number of other grass weeds found was relatively high at 22 seeds/250g. Although not specifically identified these were likely to be rye-grasses from volunteers of the previous crop.

Most of the samples with oilseed rape (OSR) in the previous cropping were winter wheat. Significantly (P=0.05) higher levels of varietal impurities were found in the plots after OSR than any other combination. Fairly high levels of other cereals were also found, mainly in winter barley samples, where on average 29 seeds/250g were found.

The use of OSR in the rotation had no significant effect on the non-cereal impurities, except for black-grass. Levels found in winter barley and winter wheat samples were equal to those from the two years of cereals regime at just over 4 seeds/250g. Ploughing as well as the normally good control of grass weeds given by OSR herbicides would probably have reduced black-grass contamination.

Straw disposal method

The issue of straw disposal is important following the straw-burning ban after harvest 1992.

The questionnaire asked what method of straw disposal was used if the previous crop was a cereal. Figure A5 shows how over the three years there were significantly higher numbers of grass weeds after burning in the swath compared to not burning (P=0.05). Non-cereal impurities were very significantly lower after chopping and incorporating compared with baling (P=0.01) and burning in the swath (P=0.001) (Table A6). Varietal impurities, mainly in barley samples in the laboratory were significantly higher after baling at over 3% compared to chopping and burning (P=0.001) and burning in the swath (P=0.05).

A general comparison of burning and non-burning gives conflicting results. Levels of other cereal and varietal impurities decreased, but weed seeds increased when burning was used (Table Aa6). Straw burning, once a convenient method of removing straw and stubble, was thought to reduce shed cereal or weed seeds. Rule (1987) showed that burning decreased the incidence of grass weeds and Cussans, Moss and Wilson (1987) demonstrated that burning reduced the incidence of volunteer cereals.

However, the same authors discussed the implications of the residues of straw burning adsorbing herbicides leading to poorer grass weed control.

Significantly lower levels of other grass weeds (P=0.05) were found in the non-burning methods, than with burning in the swath. Of the non-burning methods chopping and incorporating gave significantly lower weed seeds and fewer cereal and varietal impurities than baling.

Baling was the most popular method of straw disposal (Table A6) but had significantly higher numbers of non-cereals present than chopping and incorporating (P=0.01), and had the highest levels of varietal impurities and other cereals. The combination of baling followed by ploughing (Table Ab6) gave lower numbers of volunteer cereals, total non-cereals and black-grass compared to not ploughing. Ploughing is an important method of removing seedlings and short-lived seeds so the right combination of straw disposal with cultivation method is also important. A comparison of chopping and incorporating with different cultivation methods was not possible due to the low numbers of samples in the survey.

From the survey, therefore, the use of chopping and incorporating in reducing weed seeds in the following crop seems to be a viable alternative to burning. More work on straw disposal and cultivation method is needed in relation to species and varietal purity of grain samples.

The use of farmyard manure

The use of farmyard manure in the survey was low at 25% (Table A7). Manure was not a source of contamination of weed seeds. Indeed levels of weeds were slightly lower which could be associated with ploughing. However, varietal impurities were higher when farmyard manure was used.

Cereal seeds in the straw can be carried back into the field. As barley straw is usually used in manure, barley seeds would be the most likely contaminants and the results show a higher varietal impurity level in the barley samples (Table A7). Using farmyard manure, therefore, could be a source of varietal contamination.

The effect of cultivation method

The cultivation methods used in the survey included direct drilling as one option but as there were only two responses this method can effectively be eliminated from the analysis other than to say that it is not a popular method. Ploughing was by far the most frequent method used with 765 farmers using this compared to 115 who used minimum cultivation (Table A8).

The results generally show more impurities where minimum cultivation was used, compared to ploughing (Fig. A6). Ploughing is an established method of killing seedlings and burying short-lived seeds. Black-grass especially was higher when minimum cultivation was used, with an average of 9 seeds/250g compared to 1 seed/250g after ploughing. Sterile brome contamination was also lower after ploughing although not significantly, but common couch was at a slightly higher level, although again not significantly.

Pickett (1988) suggests that ploughing places shed grain in the lower part of the profile, thus controlling volunteers. Fewer other cereal and varietal impurities found where ploughing was used (Fig. A6).

The use of herbicides

The effect of not spraying was to increase the occurrence of total grass weeds and total non-cereals seeds (Table A9). The levels of grass weed species recorded separately, however, were not increased. Presumably if these occurred in large numbers they would have been sprayed for or removed by other methods.

Where spraying was carried out, more black-grass, wild-oats and common couch were present in the samples compared to not spraying, presumably because there would have been a weed problem originally to warrant a spraying regime. It also suggests that spraying is not totally effective.

The effect of cleaning of equipment between crops or varieties

From the results (Table A10) a higher varietal impurity level was seen both in the laboratory and in the plots, although not significantly, when no cleaning occurred. Total non-cereals and other grass weeds also occurred at higher levels. Hence, it is advisable to use cleaning equipment.

Maintenance of varietal identity

The effect of not maintaining the identification of the crop throughout resulted in the level of varietal impurities increasing to over 5% compared to 1-2% when identification was maintained (Table A11) as illustrated in Fig. A7.

Results for other species are not relevant as identification of the crop could not directly affect other impurity levels.

The effect of different grain handling systems

The handling and storage of grain are factors which could cause an admixture of varieties or cereal species. Method of grain movement did not have much influence on contamination. However, the laboratory results suggest that using an auger gives a significantly higher varietal contamination (P=0.05) than other cereals (Table A12, Fig. A8).

The effect of grain storage systems

Grain storage is a potential area where cereal contamination can occur. As illustrated in Fig. A9, storage either on the floor or in a bin after drying and cleaning gives a higher number of other cereal impurities compared to storing directly on a floor or in a bin. Varietal impurities were also found to be higher at 4.27% in the plots when stored on the floor after drying and cleaning compared to other methods (Table A13). The levels of total non-cereals were also higher at 62 seeds/250g. Since cleaning should have removed some weed seeds it must be concluded that either the majority of samples were dried and not cleaned or else that cleaning is not very effective.

Drying of the grain cannot always be avoided and cleaning is desirable to remove weed seeds and chaff and thus improve marketability of grain. It is vital, however, to ensure that thorough cleaning of the dryer and processing plant is carried out between each variety and species to keep the cereal impurities to a minimum.

Comparison of a combination of factors

Important factors are seed source, previous cropping and cultivation method.

Samples received where the seed was certified and where the previous cropping included a non-cereal and ploughing was used gave lower cereal and weed species impurities than when seed was farm-saved and the cropping was two years of cereals (Table A14, Graph A10). Further analysis to include more husbandry and grain handling techniques was not possible due to low numbers.

DISCUSSION

The main areas of interest identified from the survey were the relationships between husbandry techniques and grain contamination, and the importance of seed source. Grain handling, cleaning and storage methods were not major contributory factors.

The use of certified seed is important in maintaining lower cereal impurity levels with on average 52% more other cereal seeds found in farm-saved seed and 26% more varietal impurities. A previous cropping of two years of cereals is a major factor with significantly higher levels of all grass weed species, except sterile brome, found in the resultant grain samples. Also 90% more other cereal seeds were found than when the previous cropping was two years of non-cereals. The inclusion of a non-cereal crop in one of the two previous years generally decreases the levels of other cereals (up to 24%), varietal impurities (41%), black-grass (95%), wild-oats (84%) and common couch (77%), except for an oilseed rape rotation where higher black-grass and cereal contaminations were found.

Straw disposal methods which include burning gave 22% fewer other cereal species and 38% lower varietal impurities but 66% more grass weeds than non-burning methods. Of the non-burning methods, chopping and incorporation is a better method of reducing impurities compared to baling. The survey indicates the importance of straw disposal method in combination with cultivation method. Where ploughing was used the levels of impurities were lower compared to a minimum cultivation. Further analysis of ploughing with baling, the two most popular methods of cultivation and straw disposal, showed that this combination had levels of impurities between 43%-80% lower than baling and not ploughing. Further investigation of the interaction between straw disposal and cultivation method and the resultant grain sample purity would be worthwhile.

The survey over the harvest years 1988-1990 indicates the importance of seed source and husbandry techniques. A comparison of the best criteria, namely using certified seed, a previous cropping which includes a non-cereal and ploughing, compared to using farm-saved seed and continuous cereals shows a reduction in all impurities of between 30% and 95%.

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Heygate & Sons
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Midland Shires Farmers
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Table A1 Mean maximum and minimum contamination levels in grain samples 1988-90

Contaminant	Number of seeds found in 250g							
	Mean				Maximum			
Number of samples	SB 152	WB 155	SW 61	WW 494	SB 153	WB 155	SW 61	WW 494
<u>Species Impurities</u>								
Other cereals	13.82	23.41	5.75	5.6	1122	465	74	297
Total non-cereals	65.71	64.73	69.52	25.53	1658	1504	732	485
Sterile brome	0.35	1.61	0.82	0.41	12	79	32	20
Wild-oats	3.10	1.14	2.43	1.17	97	28	38	104
Common couch	4.67	0.23	0.64	0.96	552	16	7	454
Black-grass	2.50	4.68	2.36	1.71	197	199	75	454
Other grass weeds	34.39	39.63	12.62	7.64	1570	1262	159	426
Varietal Impurities	Varietal Impurities (% by number)							
In laboratory	2.84	3.23	0.25	0.94	100	99	6	100
Number of samples	153	155	61	494	153	155	61	494
In plots	0.35	2.76	2.91	3.06	50	100	100	100
Number of samples	148	144	61	409	148	144	61	409

(Minimum contamination levels in all categories is zero)

KEY: SB=Spring barley
WB=Winter barley
SW=Spring wheat
WW=Winter wheat

Table A2 Mean levels of contamination of grain samples intended for a feed or quality market

Contaminant	Number of seeds found in 250g		
	Quality	Feed	Significant Difference of Means
Number of samples	541	310	
Species Impurities			
Other cereals	6.71	17.59	*
Total non-cereals	41.45	56.25	-
Sterile brome	0.59	0.175	-
Wild-oats	1.72	1.56	-
Common couch	0.54	2.99	-
Black-grass	2.16	3.16	-
Other grass weeds	19.33	3.75	-
Varietal Impurities	Varietal Impurities (% by number)		
In laboratory	1.34	3.23	*
Number of samples	541	309	
In plots	2.16	3.75	-
Number of samples	481	265	

(Significant difference of P=0.05 = *
P=0.01 = **
P=0.001 = ***)

Table A3 Mean level of contamination of grain samples from crops sown with either certified or farm-saved seed

Contaminant	Number of seeds found in 250g		
	Certified	Farm-saved	Significant Difference of Means
Number of samples	746	137	
Species Impurities			
Other cereals	8.83	18.55	-
Total non-cereals	43.87	56.16	-
Sterile brome	0.56	1.08	-
Wild-oats	1.65	1.39	-
Common couch	0.82	4.85	-
Black-grass	2.66	1.29	-
Other grass weeds	19.14	18.56	-
Varietal Impurities	Varietal Impurities (% by number)		
In laboratory	1.75	2.38	-
Number of samples	746	137	
In plots	2.60	3.52	-
Number of samples	659	119	

Table A4 Mean levels of contamination of grain samples for different cleaning treatments of farm-saved-seed

Contaminant	Numbers of seeds found in 250g				
	1	2	3	4	
	Seed not cleaned	Farmer pre-clean	Mobile	Seed merchants equipment	Significant difference of means
Number of samples	16	51	73	27	
Species Impurities					
Other cereals	13.94	13.69	28.01	2.04	2**3
Total non-cereals	217.88	4.27	45.46	22.44	1*4
Sterile brome	6.13	0.24	0.56	0.04	2*3
Wild-oats	0.63	1.84	1.00	0.37	-
Common couch	2.88	10.96	0.84	0.15	-
Black-grass	0.31	1.12	1.64	0.04	-
Other grass weeds	68.81	12.33	13.99	8.63	-
Varietal Impurities	Varietal Impurities (% by number)				
In laboratory	0.5	1.8	3.11	0.11	3*4
Number of samples	16	51	72	27	
In plots	9.74	0.82	3.77	0.19	3*4
Number of samples	16	46	63	19	

Final column gives the significant difference level between the numbered columns.

Table A5 The effect of previous cropping on levels of contamination in resultant grain samples.

	Number of seeds found in 250g					
	1	2	3	4	5	
Contaminant	2 yrs cereals	Either year grass	Either year OSR	2 yrs non-cereals	Other	Significant difference of means
Number of samples	293	59	160	78	290	
Species Impurities						
Other cereals	16.46	4.0	7.56	1.72	9.37	1***2,4 1**3,3**4
Total non-cereals	68.54	49.47	31.97	45.71	29.8	1**3,5
Sterile brome	1.14	0.36	0.45	0.42	0.37	-
Wild-oats	2.93	0.63	0.89	0.49	1.16	1***2,4,1*5 1**3
Common couch	3.03	0.86	0.59	0.71	0.66	-
Black-grass	4.29	0.54	4.29	0.24	0.56	1**2,4,5
Other grass weeds	35.12	22.41	8.21	11.31	10.36	1**3,4,5 2*3
Varietal Impurities	Varietal Impurities (% by number)					
In laboratory	2.24	1.78	0.88	0.33	2.44	1**4,5*4
Number of samples	292	59	160	78	288	
In plots	2.77	2.44	4.66	1.79	1.64	3*5
Number of samples	272	53	137	72	241	

Table Aa5 (i) The effect of previous cropping on levels of contamination in resultant grain samples split into species.

Contaminant	Number of seeds found in 250g							
	2 years cereals				Either year grass			
Number of samples	SB 80	WB 97	SW 17	WW 94	SB 11	WB 7	SW 5	WW 35
<u>Species Impurities</u>								
Other cereals	6.89	30.59	6.47	10.11	0.27	11.14	16.6	2.03
Total non-cereals	89.08	70.78	71.59	32.87	65.91	32.29	131.2	37.23
Sterile brome	0.44	2.34	2.12	0.29	0.0	0.57	0.0	0.46
Wild-oats	4.53	1.34	5.06	2.80	0.18	1.0	0.0	0.63
Common couch	8.20	0.07	0.88	2.03	1.09	0.0	0.8	1.0
Black-grass	4.59	6.08	8.35	1.33	0.09	1.0	0.2	0.66
Other grass weeds	55.65	44.33	12.88	7.74	25.55	13.29	34.0	22.23
Varietal Impurities	Varietal Impurities (% by number)							
In laboratory	2.98	3.42	0.59	0.61	0.00	1.86	0.0	2.63
Number of samples	80	97	17	94	11	7	5	35
In plots	0.02	3.15	7.52	3.93	0.01	2.81	3.2	3.13
Number of samples	76	92	18	81	10	8	5	29

Table Aa5 (ii) The effect of previous cropping on levels of contamination in resultant grain samples split into species (continued)

Contaminant	Number of seeds found in 250g							
	Either year OSR				2 years non-cereal			
Number of samples	SB 3	WB 15	SW 3	WW 137	SB 9	WB 7	SW 8	WW 52
<u>Species Impurities</u>								
Other cereals	0.67	29.2	8.67	5.42	2.22	4.57	2.50	1.04
Total non-cereals	7.33	31.0	119.33	30.5	38.22	47.57	0.0	0.07
Sterile brome	1.0	0.07	0.0	0.5	0.22	1.86	0.0	0.35
Wild-oats	0.0	1.93	0.0	0.76	0.0	0.0	0.38	0.67
Common couch	0.0	1.8	0.0	0.49	0.0	0.0	0.63	0.96
Black-grass	0.0	8.27	0.0	4.02	0.0	0.57	0.0	0.29
Other grass weeds	0.67	6.4	38.67	8.03	8.78	18.86	3.13	7.69
Varietal Impurities	Varietal Impurities (% by number)							
In laboratory	0.0	6.4	0.0	0.32	0.0	0.07	0.38	0.42
Number of samples	3	15	3	137	9	7	8	52
In plots	0.03	6.15	0.0	4.23	0.0	0.29	0.01	1.67
Number of samples	3	11	3	118	9	7	8	46

Table Aa5 (ii) The effect of previous cropping on levels of contamination in resultant grain samples split into species (continued)

Contaminant	Number of seeds found in 250g			
	Other			
Number of samples	SB 50	WB 29	SW 28	WW 176
<u>Species Impurities</u>				
Other cereals	30.78	3.9	4.0	5.39
Total non-cereals	36.72	73.9	37.46	17.19
Sterile brome	0.28	0.14	0.5	0.42
Wild-oats	2.2	0.38	2.11	0.86
Common couch	0.92	0.07	0.54	0.73
Black-grass	0.3	0.03	0.04	0.74
Other grass weeds	8.94	52.48	8.57	4.30
Varietal Impurities	Varietal Impurities (% by number)			
In laboratory	3.94	2.0	0.07	1.42
Number of samples	50	29	28	176
In plots	1.01	0.58	0.97	1.98
Number of samples	50	26	27	135

Table A6 The effect of straw disposal method of a previous cereal crop on levels of contamination in grain samples.

Contaminant	Numbers of seeds found in 250g				
	1 Bales	2 Chopped/ incorporated	3 Chopped/ Burnt	4 Burnt in Swath	Significant difference of means
Number of samples	332	140	97	84	
<u>Species Impurities</u>					
Other cereals	13.62	12.39	8.65	12.31	-
Total non-cereals	47.42	26.99	46.25	99.32	1**2,2*4
Sterile brome	0.68	0.31	0.84	1.30	-
Wild-oats	1.65	2.46	1.48	1.87	-
Common couch	2.72	0.61	1.62	0.26	-
Black-grass	2.69	1.15	6.85	1.87	-
Other grass weeds	15.82	12.16	20.67	69.06	4*1,2
Varietal Impurities	Varietal Impurities (% by number)				
In laboratory	3.16	1.68	0.41	1.15	1***3 1*4
Number of samples	331	140	97	84	
In plots	2.89	2.51	2.26	2.02	-
Number of samples	302	128	81	65	

Table Aa6 Mean levels of contamination of grain samples when a non-burning method of straw disposal is compared to burning.

Contaminant	Number of seeds found in 250g	
	Non-burning	Burning
Number of samples	472	181
Species Impurities		
Other cereals	13.26	10.35
Total non-cereals	41.36	70.88
Sterile brome	0.57	1.05
Wild-oats	1.89	1.66
Common couch	2.09	0.99
Black-grass	2.23	4.54
Other grass weeds	14.73	43.13
Varietal Impurities	Varietal Impurities (% by number)	
In laboratory	2.72	0.75
Number of samples	472	181
In plots	2.78	1.71
Number of samples	430	146

Table Ab6 Mean levels of contamination of grain samples when baling and ploughing was used compared to baling and not ploughing.

Contaminant	Number of seeds found in 250g		
	Bale and plough	Bale and not plough	Significant Difference of Means
Number of samples	315	19	
Species Impurities			
Other cereals	13.01	22.89	-
Total non-cereals	46.50	61.74	-
Sterile brome	0.65	1.11	-
Wild-oats	1.68	0.89	-
Common couch	2.84	1.53	-
Black-grass	2.19	10.74	-
Other grass weeds	15.90	13.58	-
Varietal Impurities	Varietal Impurities (% by number)		
In laboratory	2.70	10.47	-
Number of samples	314	19	
In plots	2.65	6.82	-
Number of samples	288	16	

Table A7 The effect of applying farmyard manure in the previous three years on mean levels of contamination in grain samples.

Contaminant	Number of seeds found in 250g							
	No farmyard manure				Farmyard manure applied			
Number of samples	SB 101	WB 118	SW 38	WW 381	SB 49	WB 36	SW 19	WW 108
Species Impurities								
Other cereals	8.5	26.45	7.82	6.12	25.65	13.81	2.53	3.92
Total non-cereals	76.14	72.9	83.87	26.77	44.53	39.56	52.16	21.97
Sterile brome	0.31	1.97	1.03	0.4	0.45	0.44	0.58	0.45
Wild-oats	3.92	1.31	3.5	1.3	1.59	0.61	0.79	0.73
Common couch	6.5	0.27	0.89	0.96	1.16	0.11	0.26	0.94
Black-grass	3.65	5.11	3.71	2.06	0.29	3.42	0.16	0.56
Other grass weeds	41.02	47.06	10.14	7.01	19.35	16.25	19.58	10.03
Varietal Impurities	Varietal Impurities (% by number)							
In laboratory	2.58	2.8	0.37	0.63	3.55	4.86	0.05	2.09
Number of samples	101	118	38	381	49	36	19	108
In plots	0.01	2.98	3.37	2.87	1.07	2.08	2.57	3.91
Number of samples	97	111	39	316	48	32	18	88

Table A8 The effect of cultivation methods on mean levels of contamination in grain samples

Contaminant	Plough (1)	Minimum cultivation (2)	Direct drill (3)	Significant difference of means
	Numbers of seeds found in 250g			
Number of samples	765	115	2	-
Species Impurities				
Other cereals	9.24	16.98	43.0	-
Total non-cereals	43.19	59.29	297.0	-
Sterile brome	0.51	1.43	5.0	-
Wild-oats	1.59	1.70	-	-
Common couch	1.63	0.43	-	-
Black-grass	1.39	9.48	-	-
Other grass weeds	17.12	27.73	282.5	-
Varietal Impurities	Varietal Impurities (% by number)			
In laboratory	1.76	2.34	10.5	-
Number of samples	762	115	2	
In plots	2.63	2.66	0.2	3***1,2
Number of samples	680	96	1	

Table A9 The effect of herbicide on mean levels of contamination in grain samples

Contaminant	Numbers of seeds found in 250g				
	1	2	3	4	
	No herbicide	Sterile brome herbicide	Other grasses herbicide	Broad-leaved weed herbicide	Significant difference of means
Number of samples	14	75	529	801	
<u>Species Impurities</u>					
Other cereals	3.14	3.41	12.88	9.15	3,4**1,2
Total non-cereals	144.43	19.49	50.0	42.78	3,4***2
Sterile brome	0.21	1.05	0.56	0.65	4*1
Wild-oats	0.00	1.25	1.69	1.68	-
Common couch	0.71	0.39	0.65	1.50	-
Black-grass	0.36	0.36	3.27	2.66	3,4**1,2
Other grass weeds	104.29	7.56	21.14	17.53	3,4***2
Varietal Impurities	Varietal Impurities (% by number)				
In laboratory	0.0	0.71	1.22	1.84	4**2
Number of samples	14	75	527	798	
In Plots	1.66	0.22	2.84	2.51	3,4***2
Number of samples	10	66	473	711	

Table A10 The effect of ensuring that equipment is cleaned down between crops or varieties

Contaminant	1 No cleaning	2 Clean drill	3 Clean combine	4 Clean pre-cleaner	5 Clean dryer	6 Clean storage	Significant Difference of Means
	Numbers of seeds found in 250g						
Number of samples	114	705	470	192	287	441	
Species Impurities							
Other cereals	9.11	10.89	10.26	5.66	7.58	6.03	2*4,6
Total non-cereals	75.98	41.13	38.35	26.18	44.47	38.16	1,2*4
Sterile brome	0.85	0.62	0.65	0.53	0.68	0.72	-
Wild-oats	1.47	1.54	1.80	1.21	0.88	1.90	-
Common couch	0.35	1.63	0.58	0.57	2.58	0.85	-
Black-grass	0.82	2.73	3.05	3.20	2.85	3.41	2,6*1
Other grass weeds	30.75	17.73	20.58	11.45	23.71	18.54	-
Varietal Impurities	Varietal Impurities (% by number)						
In laboratory	2.75	1.67	1.28	1.59	1.69	1.11	-
Number of samples	114	702	467	192	287	438	
In plots	4.32	2.41	1.94	2.52	1.89	1.95	-
Number of samples	100	622	428	164	248	393	

Table A11 The effect of maintaining varietal identity throughout production.

Contaminant	1 Not maintained	2 At sowing	3 In Cropping	4 At Combining	5 At drying	6 In storing	Significant Difference of Means
	Numbers of Seeds found in 250g						
Number of samples	72	722	620	649	472	672	
<u>Species Impurities</u>							
Other cereals	13.13	9.92	9.98	9.57	11.83	8.65	-
Total non-cereals	46.99	45.52	46.96	47.24	48.87	44.18	-
Sterile brome	0.61	0.64	0.69	0.69	0.54	0.71	-
Wild-oats	0.51	1.80	1.85	1.92	1.87	1.83	1**2,3,4, 5,6
Common couch	1.40	1.60	1.69	1.76	2.06	0.82	-
Black-grass	0.97	2.74	2.69	2.94	3.00	3.07	1*6
Other grass weeds	11.53	20.26	21.37	20.69	20.17	19.61	-
Varietal Impurities	Varietal Impurities (% by number)						
In laboratory	5.64	1.48	1.47	1.45	1.60	1.20	-
Number of samples	72	719	617	646	469	669	
In plots	5.37	2.22	2.02	2.31	2.30	2.19	-
Number of samples	60	633	550	578	414	596	

Table A12 Mean levels of contamination of grain samples for different methods of grain handling.

	Numbers of Seeds found in 250g						
Contaminant	1 Pit	2 Auger Hopper	3 Auger	4 Chain + Flight	5 Air blower	6 Fore-end Loader	Significant Difference of Means
Number of samples	372	111	236	280	89	304	
<u>Species Impurities</u>							
Other cereals	10.89	8.3	15.57	10.65	10.08	7.74	-
Total non-cereals	35.19	53.69	50.03	39.94	58.57	48.35	-
Sterile brome	0.37	1.41	0.51	0.49	0.72	0.93	-
Wild-oats	1.57	2.30	1.72	1.69	1.93	1.65	-
Common couch	0.66	0.92	3.06	0.71	1.64	1.01	-
Black-grass	1.33	1.84	2.60	3.05	3.56	2.75	-
Other grass weeds	15.68	18.30	23.51	19.19	29.04	18.68	-
Varietal Impurities	Varietal Impurities (% by number)						
In laboratory	0.9	1.85	3.83	1.42	1.0	0.92	3*4,5,6
Number of samples	371	110	236	279	89	303	
In plots	2.46	3.11	2.38	1.93	4.67	3.27	-
Number of samples	328	95	204	249	74	267	

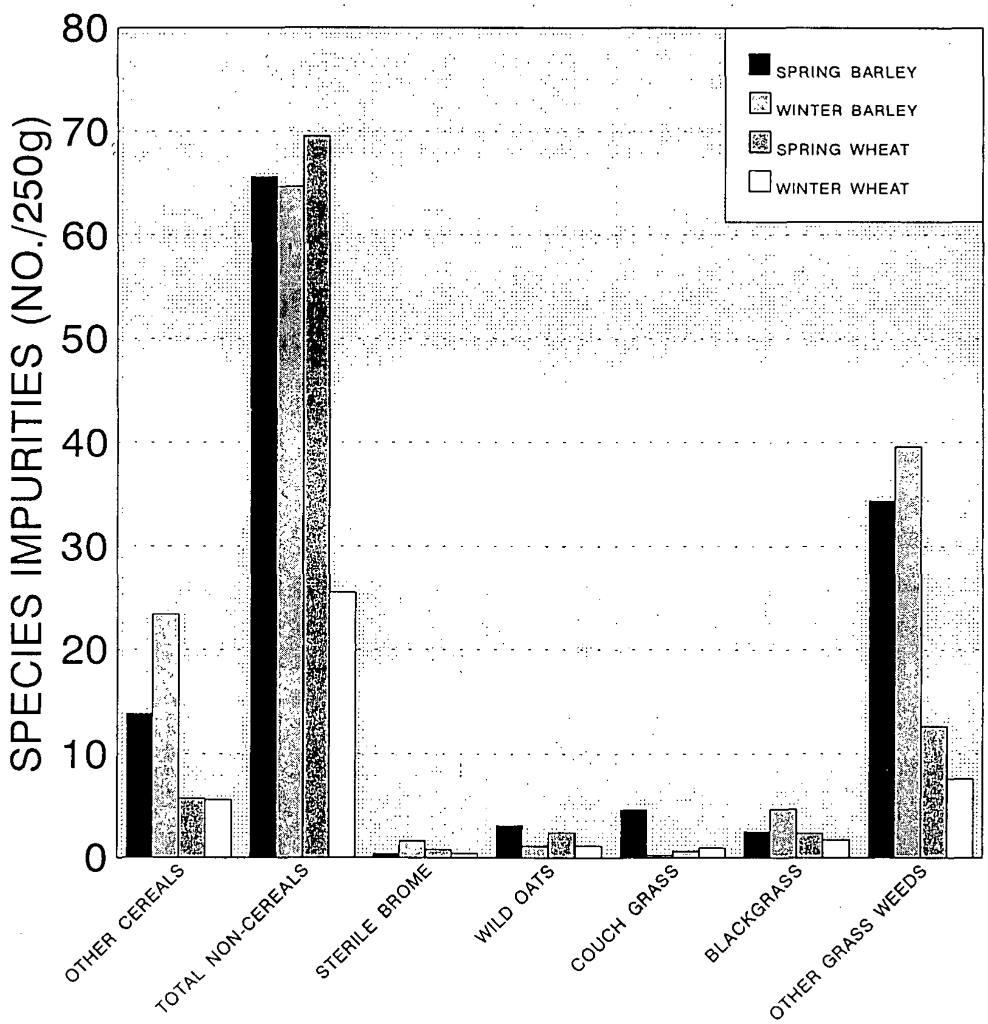
Table A13 Mean levels of contamination of grain samples for different methods of grain storage.

Contaminant	Numbers of seeds found in 250g				
	1	2	3	4	
	On to floor directly	On to floor after drying and cleaning	Into bins directly	Into bins after drying and cleaning	Significant difference of means
Number of samples	352	163	188	205	
Species Impurities					
Other cereals	6.88	11.67	8.02	16.52	-
Total non-cereals	44.91	61.94	46.46	33.34	-
Sterile brome	0.69	0.65	0.66	0.55	-
Wild-oats	2.01	1.75	1.65	1.27	-
Common couch	0.90	4.31	0.45	0.90	-
Black-grass	2.72	1.18	1.87	3.54	-
Other grass weeds	16.60	28.43	23.29	11.84	-
Varietal Impurities	Varietal Impurities (% by number)				
In laboratory	1.55	2.27	1.91	1.82	-
Number of samples	351	162	187	205	
In plots	2.93	4.27	1.32	1.83	-
Number of samples	306	145	170	176	

Table A14 Mean levels of contamination of grain samples when the best combination of factors are compared to the worst combination

Contaminant	Number of seeds found in 250g		
	Best combination of factors	Worst combination of factors	Significant Difference of Means
Numbers of samples	433	50	
<u>Species Impurities</u>			
Other cereals	4.22	11.36	*
Total non-cereals	30.16	78.02	-
Sterile brome	0.14	2.60	-
Wild-oats	1.08	2.80	-
Common couch	0.74	12.22	-
Black-grass	0.56	2.66	-
Other grass weeds	9.2	34.58	-
Varietal Impurities	Varietal Impurities (% by number)		
In laboratory	1.54	3.02	-
Number of samples	433	50	
In plots	2.72	3.90	-
Number of samples	376	47	

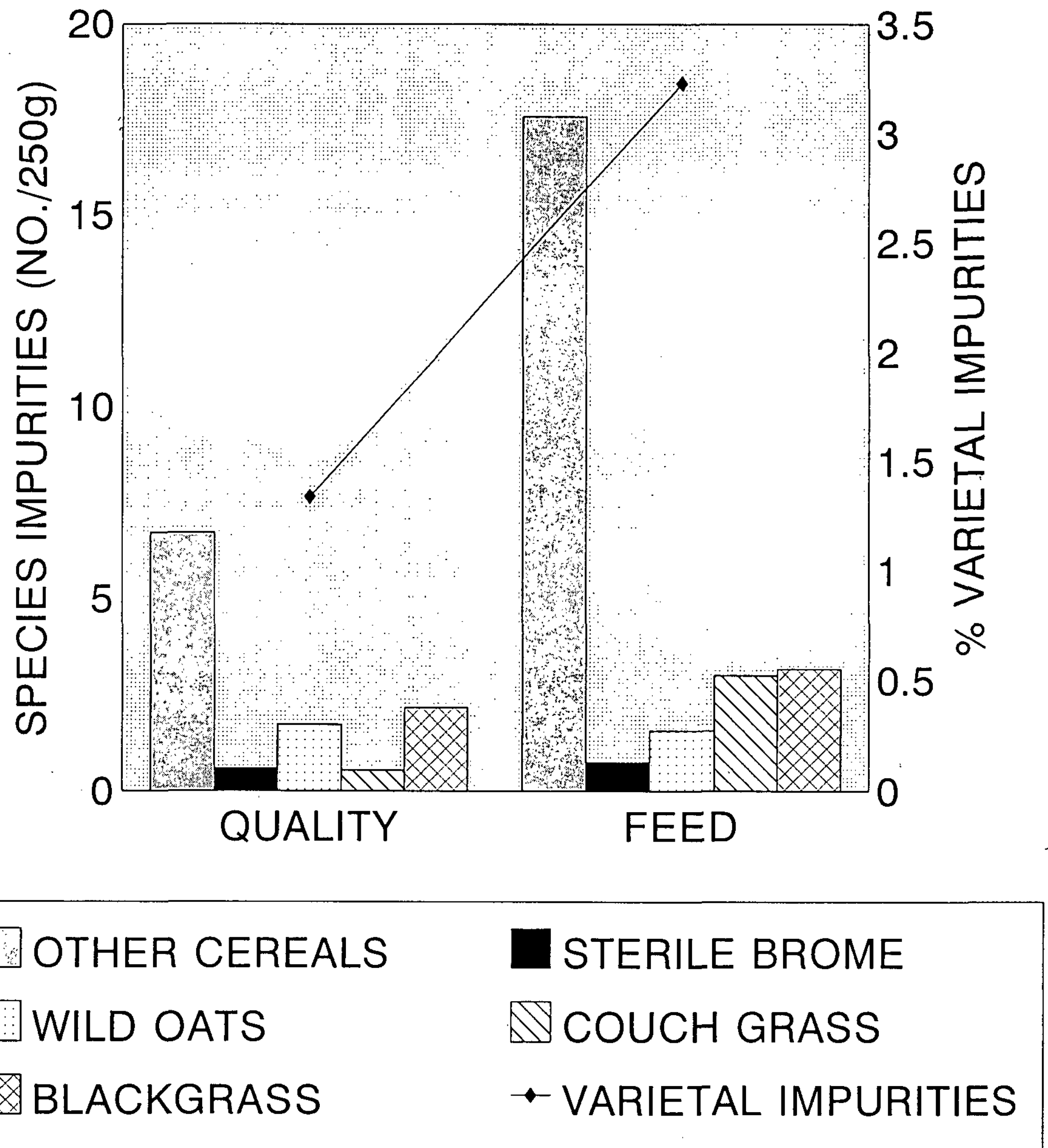
MEAN CONTAMINATION LEVELS
HARVEST 1988-1990



MEAN LEVEL OF VARIETAL IMPURITIES (LABORATORY DATA):
SPRING BARLEY - 2.84% WINTER BARLEY - 3.23%
SPRING WHEAT - 0.25% WINTER WHEAT - 0.94%

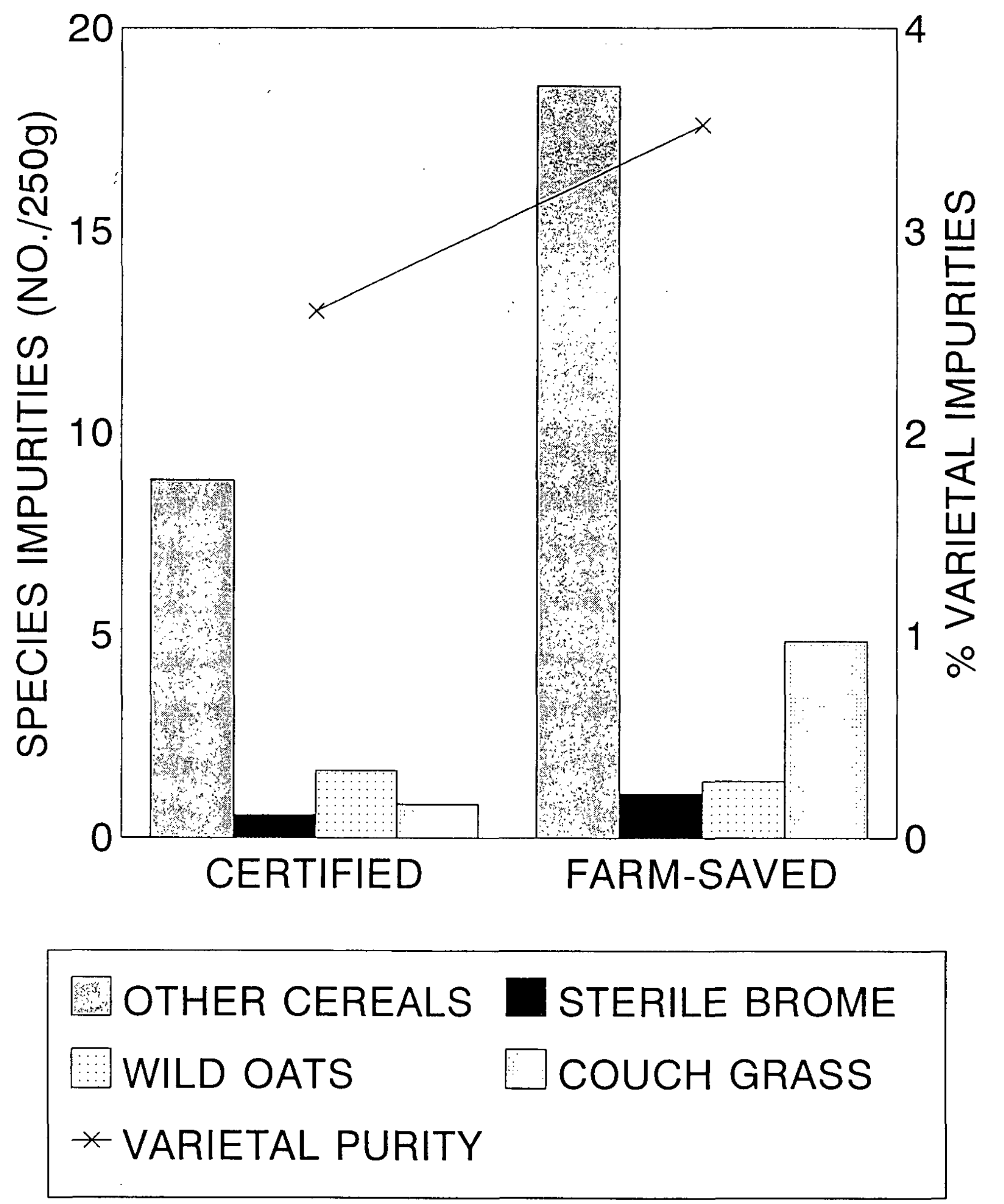
GRAPH 2

INTENDED MARKET
MEAN CONTAMINATION LEVELS



% VARIETAL IMPURITY TAKEN FROM LABORATORY DATA

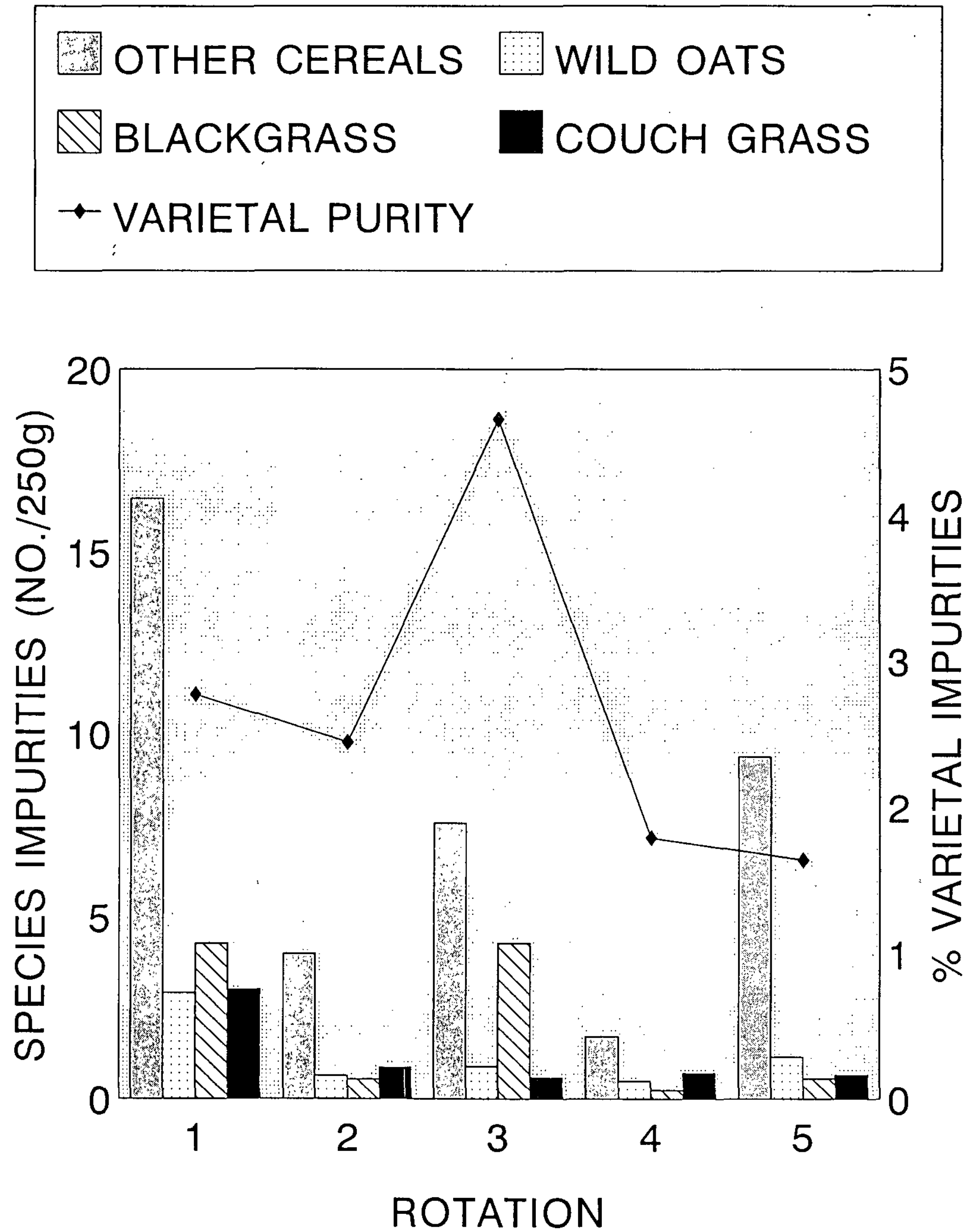
CERTIFIED OR FARM-SAVED SEED
MEAN CONTAMINATION LEVELS



%VARIETAL IMPURITY TAKEN FROM PLOT DATA

GRAPH 4

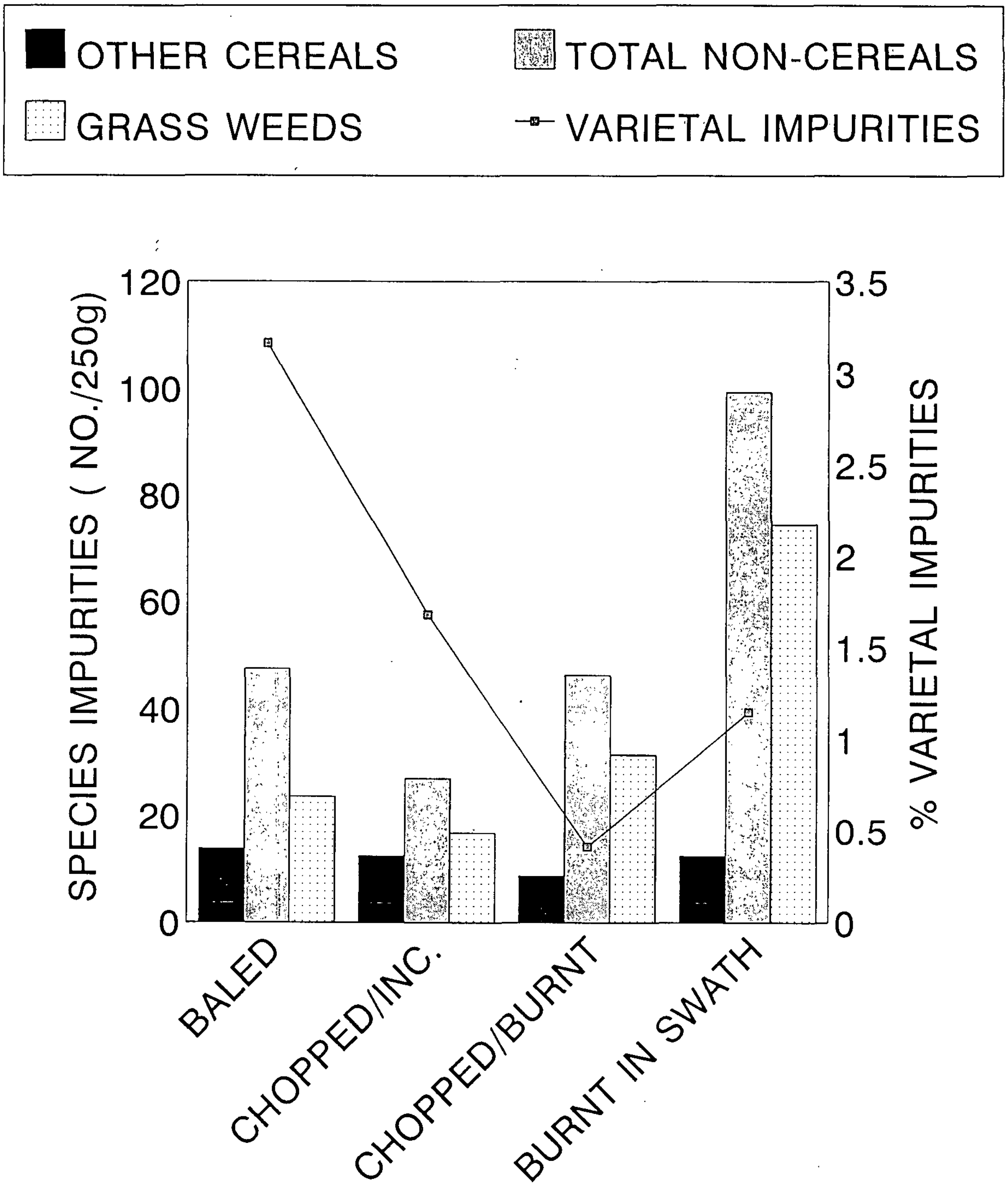
PREVIOUS CROPPING
MEAN CONTAMINATION LEVEL



VARIETAL IMPURITY LEVELS FROM PLOT RESULTS
1= TWO YEARS CEREALS; 2= EITHER YEAR GRASS; 3= EITHER YEAR OILSEED RAPE; 4= TWO YEARS NON-CEREALS; 5= OTHER

GRAPH 5

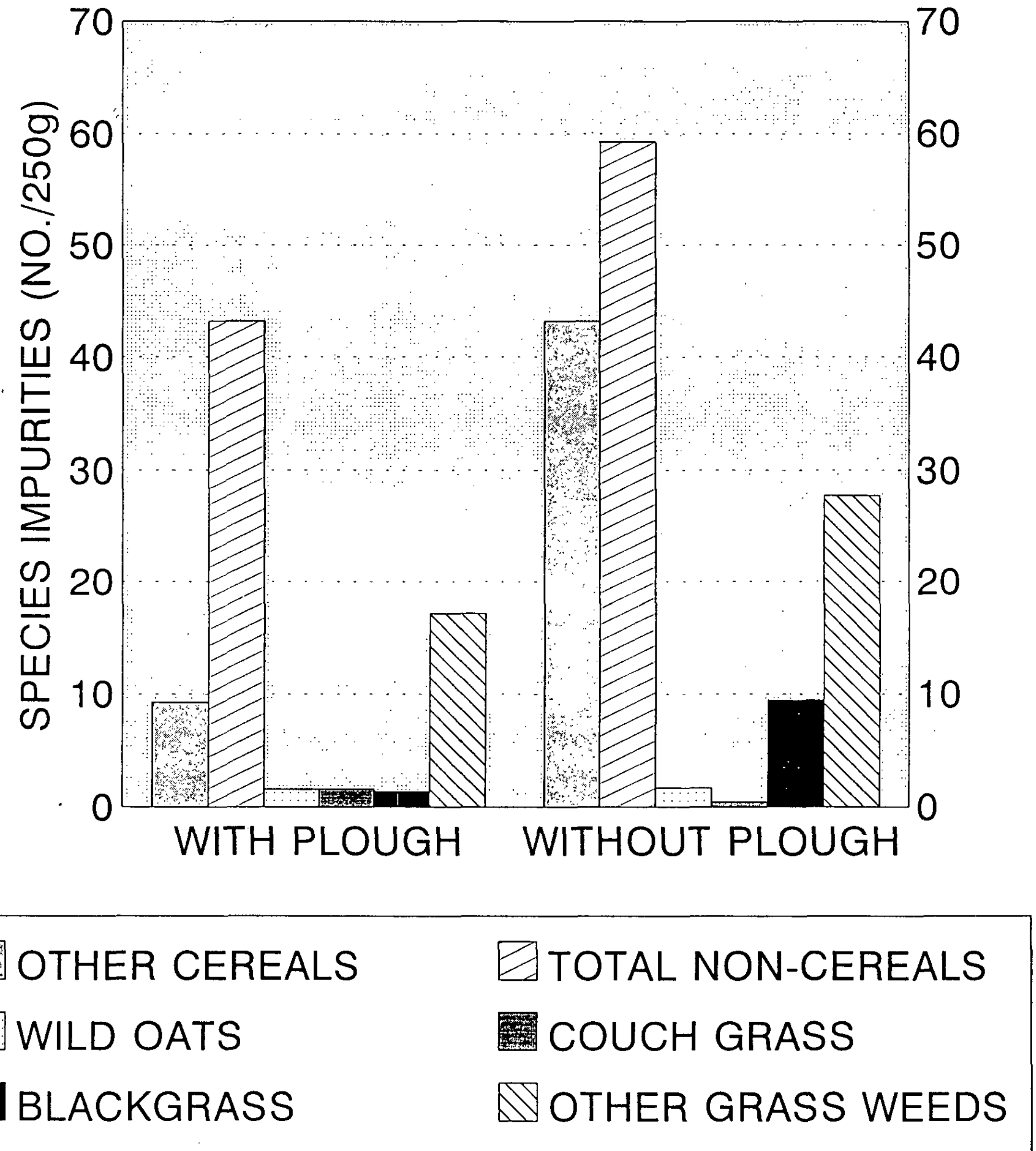
STRAW DISPOSAL METHOD
MEAN CONTAMINATION LEVELS



% VARIETAL IMPURITIES TAKEN FROM LABORATORY DATA

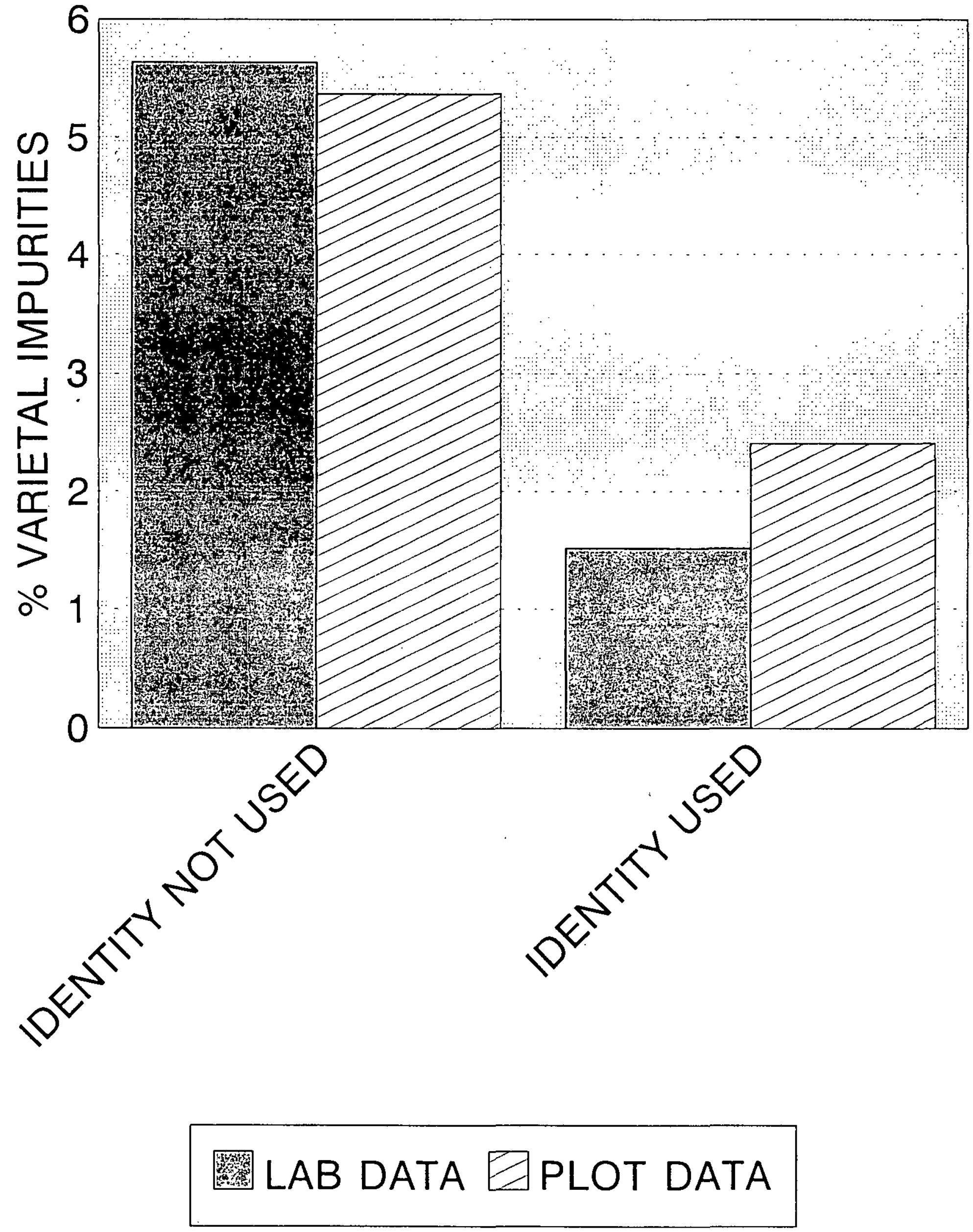
GRAPH 6

CULTIVATION METHOD
MEAN CONTAMINATION LEVELS



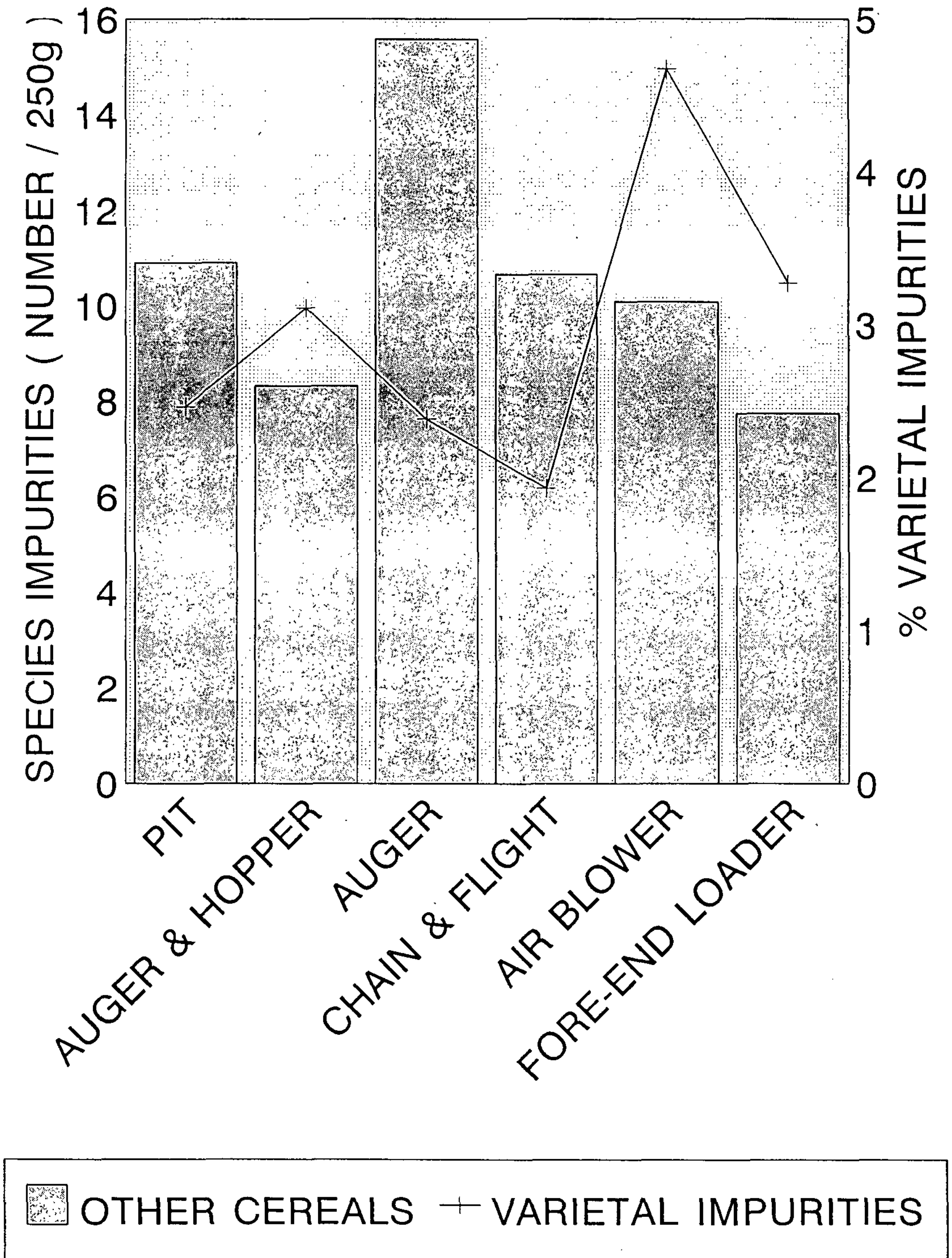
GRAPH 7

MAINTENANCE OF VARIETAL IDENTITY
EFFECT ON VARIETAL PURITY



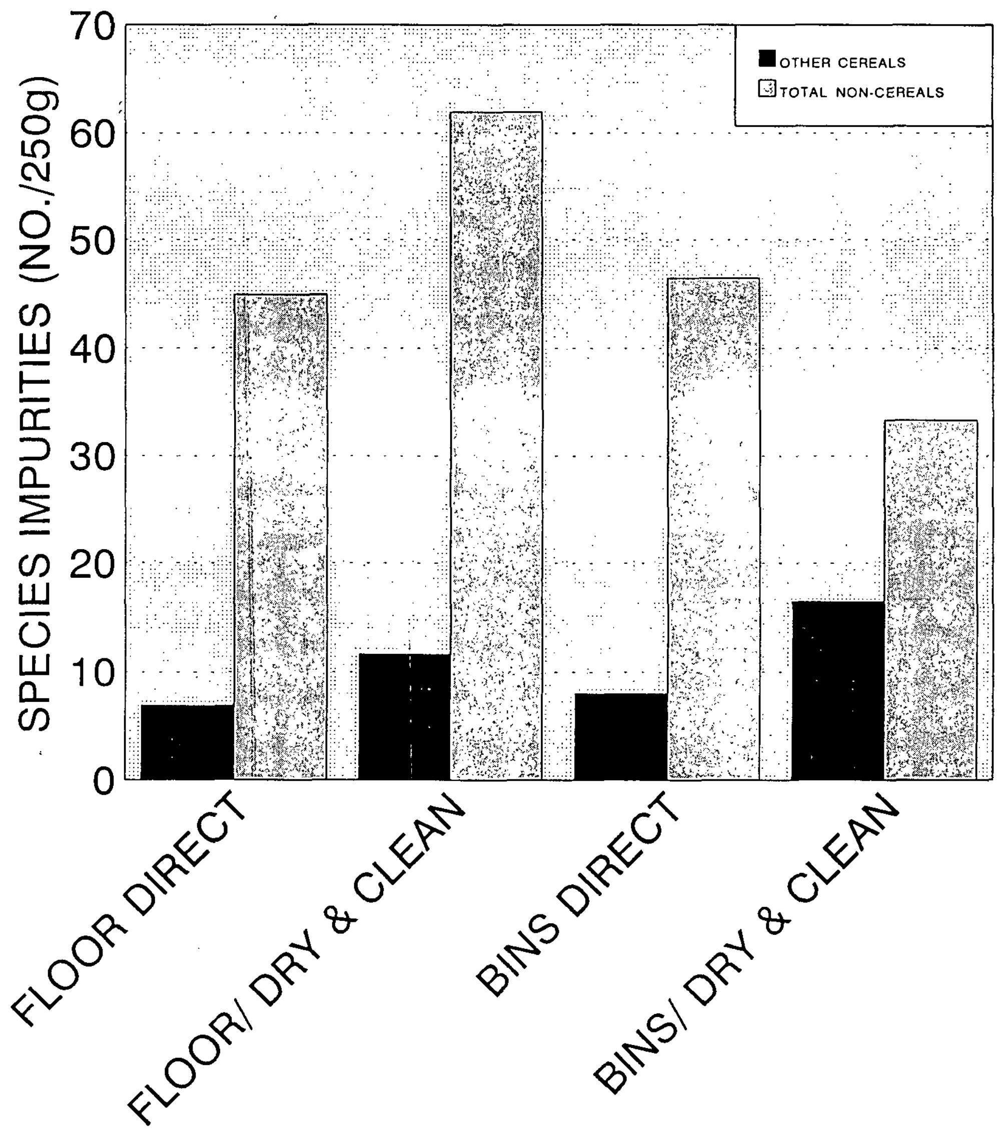
GRAPH 8

EFFECT OF GRAIN HANDLING METHOD
ON MEAN CONTAMINATION LEVELS



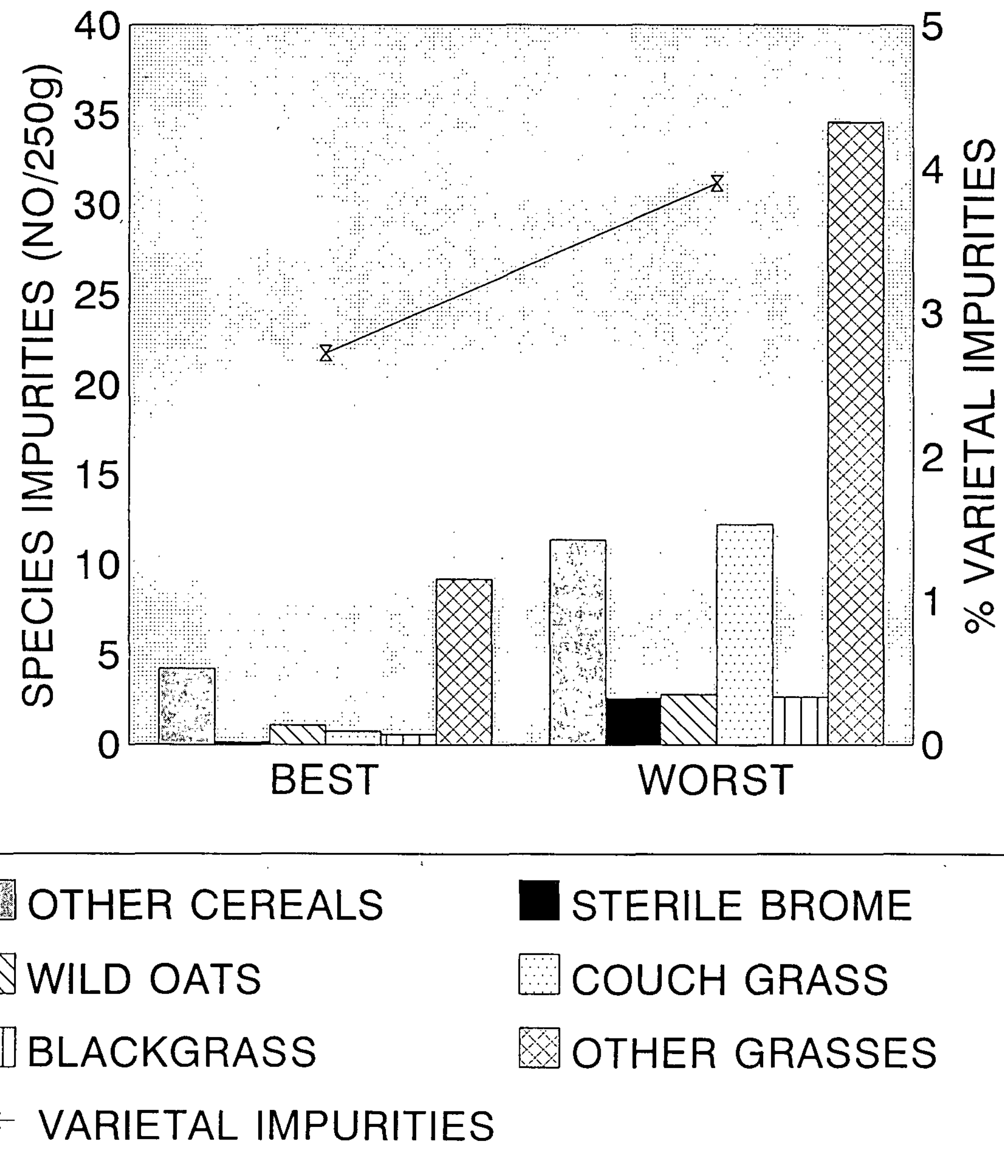
% VARIETAL IMPURITIES TAKEN FROM PLOT DATA

GRAIN STORAGE METHOD
MEAN CONTAMINATION LEVELS



GRAPH 10

MEAN CONTAMINATION LEVELS COMPARING BEST AND WORST COMBINATION OF FACTORS



% VARIETAL IMPURITY TAKEN FROM PLOT DATA
BEST: CERTIFIED SEED,FOLLOWING A NON-CEREAL, PLOUGH
WORST: FARM SAVED SEED, FOLLOWING 2 YEARS CEREALS

PART B

EFFECT OF CULTIVATIONS AND HERBICIDES ON THE OCCURRENCE OF VOLUNTEER CEREALS

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ABSTRACT

This project examined the factors affecting the occurrence of volunteer cereals, in cereal sequences and identified the most effective methods of control. The main infestation occurred in the following crop but recurred for several years after the parental crop. Straw incorporation experiments consistently demonstrated that burning most effectively reduced the number of volunteers and ploughing provided the best alternative. Cultivation and herbicide comparison experiments confirmed the results of the straw incorporation experiments. When non-plough cultivation was used, good control can be achieved by using a herbicide prior to sowing the next crop. Reliance on tine or rotary cultivation as the sole means of control was unsatisfactory, except in the dry 1989 season.

During much of the period of study there were drier than average seasons. This may have influenced the degree of infestation recorded and may not, therefore, be typical. However it is doubtful if seasonal effects unduly influenced the overall effect of different tillage methods.

Shed seeds which are dormant at harvest may not germinate until after the following crop has been sown, and are therefore very difficult to control. The spring barley studies confirmed that varieties vary in their expression of dormancy, and also that dormancy can vary considerably from season to season, in response to weather conditions during the grain filling period. A well grown crop will help suppress tillering of volunteer plants and thereby reduce the amount of contamination at harvest. The Rothamsted long-term straw incorporation experiment in 1990 did however

provide some evidence, albeit circumstantial, that ploughing each year may return to the surface a very small amount of viable seed which has been buried in previous years.

INTRODUCTION

Volunteer cereal plants grow from seed shed before or during harvest to infest subsequent crops. Most infestation occurs in the crop immediately following, but it can continue for several years when volunteers themselves shed seed. There is however, a small possibility that some seed may remain viable in the soil long enough to grow in the next crop but one (Rauber, 1987).

The problem of volunteers has become more serious in recent years due to the dominance of autumn-sown compared to spring-sown crops, less emphasis on rotations and changes in methods of straw disposal. The market demands quality, so for milling wheat, a small degree of contamination by a feed variety will have a disproportionately large adverse effect on Hagberg Falling Number. Similarly with malting barley, contamination with a feed variety will increase grain %N, and in the case of crops grown for seed, a species purity of 99.9% in the field is necessary to avoid rejection.

The ban on the burning of cereal straw after the 1992 harvest is the culmination of gradual changes in recent years, with more straw being incorporated (MAFF, 1984 & 1989). Some farmers are incorporating straw with tine and disc cultivation rather than ploughing; one consequence of this has been an increase in volunteer cereals.

OBJECTIVES

The objectives of this project were: to evaluate different methods of straw disposal and soil cultivation on the occurrence of volunteers in the following crops and; to identify appropriate methods of control to improve grain quality in terms of varietal and species purity when straw is not burnt.

The presence of foreign cereal grains in harvested grain is a function of a number of largely independent factors. These include: the degree of pre-harvest shedding of grain; harvesting losses; the straw disposal method; the degree of dormancy in shed seed; the choice of cultivations prior to the sowing of the following crop and competition for growth by the sown crop.

The experimental work of this project studied many of these factors, and consisted of three parts, which will be discussed separately. These were: a survey of existing straw disposal experiments to see which treatments produced the lowest numbers of volunteers; experiments to find the best methods of chemical or mechanical control and studies of grain dormancy of different spring barley varieties in different years.

STRAW DISPOSAL EXPERIMENTS

Methods

Eight field experiments in four locations were surveyed, some over four years. Where possible the number of volunteer ears was assessed at anthesis, using floating quadrats. Details of the experiments and assessments are given in Table B1. Experimental records were also used to provide data from experiments carried out prior to 1988.

Results and discussion

Results of assessments are shown in Table B2, and in Figures B1-B8. Overall, burning straw and stubble was the most effective way to reduce volunteers, irrespective of the method of subsequent cultivation. The effectiveness was dependent on the quality of the burn. In one experiment at Rothamsted in 1986 a poor burn in the previous autumn followed by shallow tine cultivation provided no better control than incorporating the straw by the same method (Fig. B1).

The effect of straw disposal without the use of tillage could only be compared in the long-term cultivation experiment at Northfield, Oxfordshire (Fig. B3). Results in both

1987 and 1988 clearly showed the advantage of burning over chopping straw when a crop is direct drilled.

Differences between baling and chopping

Only at two sites, the Northfield long-term straw incorporation experiment (Fig. B3) and West Barnfield (Table B3) could this comparison be made. Baling straw did not lead to a reduction in volunteers.

Method of incorporation

Ploughing was more effective than tine cultivation in reducing volunteers. A comparison of tine cultivation and ploughing to 10 cm or 20 cm carried out at both Rothamsted on a clay soil, and Woburn on a sandy soil, clearly demonstrated the difference between the two methods (Figures B1 & B2). In 1986 at both sites up to 30% of ears present on the tined plots were derived from volunteer plants. Land that had been ploughed had on average 1.3% volunteer ears at Rothamsted and 4.5% at Woburn.

At Whaddon in 1986, on plots where straw was chopped there were considerably more volunteer barley plants after tine cultivation than after ploughing. Although the ratio (tine:plough) was nearly the same on the burnt plots, the average number of volunteers was only about half that of the chopped plots (Fig. B4).

Depth of Incorporation

In 1987 at Northfield, where three depths of ploughing were compared, increasing depth of ploughing increased the effectiveness of volunteer control. On plots where straw was burnt, the main difference was between direct drilling and ploughing to 5 cm which were similar at about 10% volunteers, and ploughing to 15 cm and 25 cm where the average was 4.5% (Fig. B3). The ploughing of stubble to a depth of 5, 15 or 25 cm reduced the volunteers from nearly 27% to 15% to 12% respectively. When chopped straw was ploughed in, the percentage of volunteers for the corresponding depths were approximately 26%, 12% and 11% respectively.

Time of incorporation

In one Rothamsted experiment between 1987 and 1991, a three week delay in the incorporation of straw had the effect of increasing % volunteers compared with an earlier incorporation. The same was true after burning the straw (Table B3). In 1986, when a greater number of volunteers was recorded than in other years, there were more volunteers after later cultivation on the burnt plots, but on the incorporated plots, the largest numbers were after the earlier incorporation.

Amount of straw

In three experiments in 1987 the percentage of volunteers increased with increasing amounts of straw. However, the rate of increase was not proportional to the amount of straw (Figures B5 & B6). Differences were small in 1988, suggesting that little grain was held in the straw that was used on these plots. The higher percentages of volunteers on the 20 t/ha treatment was due to a clump of volunteers in one quadrant assessment. It is thought to be due to the shedding of an ear containing grain. In 1989 at both Rothamsted and Woburn, there was no valid evidence that volunteers increased in proportion to the amount of straw (Table B4). This suggests that table and sieve losses were more important than concave and straw walker losses.

Effect of a rotational break

At one site, Whaddon, a crop of winter oilseed rape separated two cereal crops; winter barley in 1986 and winter wheat in 1988. Barley volunteers recorded in the wheat, represented about 1 ear in 400 (Fig. B4). Barley volunteers were found in the oilseed rape crop in November 1986, on tine cultivated and ploughed plots there were 1.5 and 0.3 plants m^{-2} respectively on the burnt straw areas, and 0.9 and 0.5 plants m^{-2} respectively on the chopped straw areas and these plants are thought to be the source of barley plants in the following wheat crop.

Carry over in cereal crops

The long-term straw incorporation experiments (Experiment 1, Table B1) demonstrate the carry over of one variety in succeeding cereal crops. Winter wheat, cv. Avalon was harvested in the summer of 1985 and followed by three successive wheat crops, cv. Mission. The difference in appearance between these varieties made it possible to distinguish one from the other. At Rothamsted, Avalon could still be found in the third crop of Mission on all treatments except the chop/tine plough (Fig. B1). At Woburn, only on the chop/tine 10 cm plots was any found in the third year (Fig. B2).

In 1990, Rendezvous, the cultivar used in 1989, proved to be indistinguishable from the sown crop, cv. Pastiche, so it was not possible to assess the number of volunteers arising from previous year's crop, but a small number of plants of cv. Mission, used in 1988, were found and assessed (Table B2). The numbers of Mission volunteers surviving from 1988 were always small, nearly all less than 1%. At Woburn the results were inconsistent and not significant, but at Rothamsted significantly ($P<0.01$) more volunteers were found after ploughing alone. This raises the possibility that the plough treatment in 1990 was returning viable seeds to the soil surface which had been buried by ploughing in the previous year.

CULTIVATION AND HERBICIDE EXPERIMENTS

Methods

In experiments on stubble land in 1988-1991, a range of primary cultivations, followed by a second cultivation with or without the supplementary application of a contact or translocated herbicide were used before sowing a different cereal crop. The crop sequences studied were: winter wheat after winter barley, winter barley after winter wheat and winter wheat after spring barley.

The number of volunteer plants that were present before the next crop was sown was measured using a 0.25 m x 0.25 m quadrat. At least six measurements were taken per plot. At anthesis, ears of both the volunteers and the sown crop were counted using a floating quadrat. Three paired quadrats per plot were measured. Finally, from the grain harvested from each plot, two 100 g samples were taken from a larger sample taken from the combine and the number of volunteer grains were separated and weighed.

In each of the four years when crop sequences were compared, the lowest number of volunteers were found in winter wheat after spring barley, and the largest number were in winter wheat after winter barley except in 1991 (Table B9). This is presumably because winter barley matures before wheat and more grain is collected but when barley follows wheat some wheat grain is green and immature and is screened out on the combine sieves. Spring barley plants are less of a problem because the time between the harvest of a spring crop and the sowing of a following winter crop is insufficient for the volunteers to become established, and are more easily controlled by stubble cultivations, non-selective herbicides or competition from the succeeding crop.

Results

As expected, all experiments showed that ploughing was the most effective control method. The effectiveness of the other combinations of treatments was variable, and depended on the weather conditions. Applying a supplementary herbicide gave consistently better results as a pre-sowing treatment than the rotary harrow alone, although they performed relatively poorly in 1989, the only year when the rotary harrow performed relatively well (Tables B5 & B6). This variation in performance appears to be related to the moisture content of the seedbed. When the seedbed is moist and volunteer plants are actively growing, they can be readily killed by the translocated or contact herbicide. The rootballs of plants uprooted by the rotary or tined cultivation treatments remained moist and many re-establish themselves, resulting in poor control when no supplementary spray was applied. This happened in 1988 (Table B7). In contrast, with a dry seedbed, plants not actively growing are less easily controlled by the herbicides, whilst plants uprooted rapidly become desiccated and die.

The large variation (annual basis) in numbers of volunteers on experiments is due mainly to seasonal weather differences.

In 1989 hot weather coincided with ripening and led to an early harvest. This was followed by a dry autumn. The combination of weather factors and the longer break between harvest and the next crop being sown may be the reason for low levels of infestation in the 1990 harvest (Table B8). Some experiments had few or no volunteers present at anthesis and consequently are not reported here.

Throughout the four years, no consistent difference was found between the effectiveness of either the translocated herbicide (glyphosate) or the contact herbicide (paraquat). Similarly, in 1990 and 1991, when two cultivation dates were used, no consistent differences were found between them.

It was observed in both these and the straw incorporation experiments that the number of volunteer ears present in the crop at anthesis appeared to be inversely proportional to the density of the sown crop. In order to examine this, with data from the Bylands site (barley following winter wheat) in 1989, a generalised linear model with Poisson error was fitted, relating the number of volunteer ears present to the exponential of a linear function of sown crop density, taking into account primary and pre-sowing treatments. The latter did not improve the fit, and were left out of the model.

Figure B7 shows a simple model allowing different intercepts for primary cultivations and one common slope. Despite a wide scatter of data points, especially for ploughing, where there were many low volunteer counts, the model shows a decrease in the number of volunteer ears as the number of ears of the sown crop increases.

Discussion

The model thus shows that with each cultivation method, the better the sown crop is established, the fewer volunteer ears will be present and this will result in lower grain contamination at harvest. This suggests that seedbed quality may also be affecting the number of volunteer ears present. Volunteer control may therefore be dependent on two factors. Firstly, the cultivation method directly influences the number of volunteer seeds that survive and become plants, and secondly the seedbed quality affects establishment of the sown crop. When the sown crop is poorly established, volunteer plants can exploit gaps and produce more tillers. The model was tested on other data sets but where there are insufficient number of volunteers fit is poor.

GRAIN DEVELOPMENT AND DORMANCY EXPERIMENTS

Methods

In three experiments at Rothamsted in 1989, 1990 and 1991, ears of two spring barley cultivars were sampled twice weekly from anthesis to maturity. Grains were then excised and tested for viability and dormancy in moist sand using a modification of official seed testing methods (ISTA, 1985). The two cultivars were chosen for their known differences in dormancy characteristics. The feed variety Klaxon was used in all three years, and compared with the malting varieties Natasha (1989) and Triumph (1990, 1991) which have often been reported to suffer from problems of dormancy.

Results

The pattern of % viability, % dormancy and % moisture content in the grain samples are shown in Figures B8-B10. In all three years, at least 50% of the grains were capable of germination by 10 days after anthesis, but were deeply dormant. In 1989 and 1990 the dormancy of both varieties remained virtually 100% until approximately one month before maturity, when it fell rapidly, and little dormancy remained in the Klaxon samples at harvest.

In 1989 there was little difference between the two varieties, but in the other two years Triumph remained dormant longer than Klaxon. In 1991 the fall in dormancy occurred much later, so that the samples were 23% and 89% dormant at harvest for Klaxon and Triumph respectively.

Discussion

The results demonstrate a situation common in the cooler northern parts of this country which causes problems for maltsters. The prolonged dormancy may have been associated with a cool May and June, which had mean maximum temperatures 2°C and 3°C below the 30 year mean respectively, and in spite of the fact that July and August were warmer than average.

ACKNOWLEDGEMENTS

We wish to thank our colleagues at Rothamsted for their help, in particular, Miss A Buck, Miss N Yates, Mr E Bacon and Mr A Todd. We are grateful to the farm staff at Rothamsted and Woburn for managing the field experiments.

Table 1B Straw disposal experiments surveyed for volunteer cereals

	Treatments	
Experiment number, title, location and year	Straw disposal methods	Primary cultivation and depth (cm)
1. *Long-term straw incorporation* Rothamsted and Woburn 1986-1991	burn chop	tine, 10 tine, 10 + plough, 20 tine, 10 + tine, 20 plough, 20
2. *Effects of shallow incorporation* Rothamsted 1987, 1988, 1990, 1991	burn, bale, chop time of incorporation	tine, 10
3. *Amount of straw* Rothamsted and Woburn 1987-1989	different amounts of straw	plough, 25(R) tine, 20 (W)
4. *Amounts of straw* Northfield, Oxon 1987, 1988	straw (t ha^{-1}):- 0, 5, 10, 15, 20	tine, 15
5. *Long-term straw disposal* Northfield, Oxon 1987, 1988	burn, bale, chop	direct drill plough, 5, 15, 25
6. *Whaddon, Bucks* 1986-1988	burn chop	tine/rotary cultivation, 15 plough, 154

Table B2, Experiment 1. The effect of straw disposal and cultivation method on the occurrence of volunteer cereals 1990 (% volunteer ears at anthesis)

	Cultivation method and depth (cm)			
Straw disposal	tine, 10	tine, 10 tine, 20	tine, 10 plough, 20	plough, 20
Rothamsted (Great Knott) clay loam soil				
Burn	0.0	0.0	0.0	0.9
Chop	0.0	0.3	0.2	0.4
LSD (P = 0.05)				0.47
Woburn (Far Field) sandy loam soil				
Burn	0.0	0.6	0.5	0.2
Chop	0.4	1.3	0.2	0.7
LSD (P = 0.05)				1.34

Table B3, Experiment 2. Effect of straw disposal and timing of cultivation on the occurrence of volunteers at anthesis 1986.

Straw disposal	Cultivation time	
	Early	3 weeks later
	% volunteer ears	
Burnt	4.8	6.5
baled	11.4	14.1
chopped	10.7	10.1

Table 4B, Experiment 3. The effects of the amount of straw on the occurrence of volunteer cereals, 1989

	Rothamsted		Woburn	
Straw	Straw weight t ha^{-1} @ 85% DM	% volunteer ears	straw weight t ha^{-1} @ 85% DM	% volunteer ears
None	-	0.8	-	3.9
Normal	3.3	0.1	5.8	5.8
Normal x 2	6.6	1.3	11.6	4.4
Normal x 4	13.2	2.6	23.2	3.7
LSD (P = 0.05)		1.66		3.05

Table B5. The effect of cultivation and herbicides on the occurrence of volunteer cereals, 1989. Winter wheat after winter barley

	Pre-sowing Treatments								
	GL	PA	RH	GL	PA	RH	GL	PA	RH
	Autumn volunteers m^{-2}			Anthesis % volunteers ears			Harvest % Contamination		
Primary cultivations									
None	32	4	37	16	15	8	9.2	9.0	7.2
Dynadrive	31	11	53	4	7	7	4.3	4.2	4.8
Disc cultivation	31	4	65	4	5	9	2.9	3.1	5.0
Plough	<2	0	4	<1	2	2	0.3	0.7	0.8
Rotary cultivation	31	7	41	1	2	4	1.7	1.6	2.9
Tine	12	4	37	8	7	5	3.8	3.6	4.7
S.E.D.			19.1 (10df)			3.5 (20 df)			2.2 (20 df)

GL - glyphosate, PA = paraquat, RH = rotary harrow

Table B6. The effect of cultivation and herbicides on the occurrence of volunteer cereals, 1989 winter barley after winter wheat

	Pre-sowing Treatments								
	GL	PA	RH	GL	PA	RH	GL	PA	RH
	Autumn volunteers m^{-2}			Anthesis % volunteers ears			Harvest % Contamination		
Primary cultivations									
None	11	44	33	6.6	3.4	13.2	5.1	4.2	6.3
Dynadrive	9	23	23	2.0	3.0	3.4	1.7	1.9	1.6
Disc cultivation	6	16	20	8.4	3.7	6.5	1.8	2.6	2.0
Plough	10	37	31	0.5	0.7	1.4	0.2	0.3	1.0
Rotary cultivation	7	25	20	1.1	1.2	2.0	0.8	0.7	1.2
Tine	7	39	20	2.1	2.0	2.3	1.5	1.9	3.4
S.E.D. (20 d.f.)			10.5			2.7			1.66

GL - glyphosate, PA = paraquat, RH = rotary harrow

Table B7. The effect of cultivation and herbicides on the occurrence of volunteer cereals, 1988. Winter wheat after winter barley

	Pre-sowing Treatments								
	GL	PA	RH	GL	PA	RH	GL	PA	RH
	Autumn volunteers m^{-2}			Anthesis % volunteers ears			Harvest % Contamination		
Primary cultivations									
None	8	3	70	6	4	25	4.8	5.7	11.3
Dynadrive	7	4	92	4	<1	27	3.5	3.3	12.6
Disc cultivation	4	6	111	5	2	30	4.2	3.3	13.3
Plough	<1	<1	20	<1	<1	9	1.9	1.8	5.0
Rotary cultivation	<1	4	89	4	<1	24	7.5	9.8	10.8
Tine	3	6	86	2	4	23	4.1	3.1	14.1
S.E.D. (20 d.f.)			9.46			4.29			3.67

GL - glyphosate, PA = paraquat, RH = rotary harrow

Table B8. The effect of cultivations and herbicides on the contamination of grain harvest, 1990.

		Winter wheat after winter barley			Winter barley after winter wheat		
		Pre-sowing treatment[b]			Pre-sowing treatment		
		GL	PA	RH	GL	PA	RH
Primary cultivations and timing[a]		% Contamination			% Contamination		
None	early	1.1	2.1	6.8	0.4	0.4	2.2
	late	1.3	1.9	7.5	0.5	0.3	3.3
Dynadrive	early	0.8	1.3	9.9	0.3	0.1	2.5
	late	0.7	1.0	9.7	0.3	0.2	0.3
Plough	early	0.2	0.3	0.7	<0.1	0.1	<0.1
	late	<0.1	0.1	0.4	0.5	0.3	0.2
Tine	early	0.4	1.0	9.1	0.4	0.2	2.0
	late	0.4	0.7	7.9	0.4	0.4	0.8
S.E.D. (28 d.f.)				2.03			0.682

[a]Early = as soon as practical after harvest and 3 weeks later.
[b]GL = Glyphosate, PA = Paraquat, RH = Rotary harrow

Table B9. The effect of cultivations and herbicides on the contamination of grain at harvest, 1991.

		Winter wheat after spring barley			Winter wheat after winter wheat			Winter barley after winter wheat		
		Pre-sowing treatment[b]			Pre-sowing treatment			Pre-sowing treatment		
Primary cultivations and timing[a]		GL	PA	RH	GL	PA	RH	GL	PA	RH
		% Contamination			% Contamination			% Contamination		
None	early	2.1	2.4	4.6	4.9	7.4	16.4	20.8	13.2	19.7
	late	0.8	2.0	3.5	3.7	5.5	13.9	22.5	12.4	13.3
Dynadrive	early	2.1	3.1	4.8	3.8	5.6	19.9	12.8	14.9	16.4
	late	1.3	2.3	2.0	6.2	3.4	18.5	11.2	13.0	17.6
Plough	early	0.2	0.2	0.2	0.5	0.2	2.6	2.7	2.4	3.2
	late	0.1	0.2	0.1	0.2	0.3	1.8	0.9	0.5	0.7
Tine	early	2.2	2.8	3.8	4.2	3.8	19.8	16.0	14.3	12.6
	late	1.7	3.0	2.6	4.7	5.5	16.1	17.2	11.7	14.9
S.E.D. (28 d.f.)				1.21			3.04			4.06

[a]Early, as soon as practical after harvest and 3 weeks later.
[b]GL - glyphosate, PA = paraquat, RH = rotary harrow

PART C

THE EFFECT OF CULTIVATION AND SOIL TYPE ON THE SEED VIABILITY OF MEADOW AND STERILE BROME AND VOLUNTEER CEREALS

P.B. Bowerman, ADAS Boxworth

ABSTRACT

The two experiments were started in September 1988, each with a site at ADAS Boxworth and ADAS Bridgets. The objective was to determine the effect on seed viability of barren brome, meadow brome and volunteer cereals (particularly winter barley) of different types when tined cultivation or ploughing at various depths were used over a three year period on two contrasting soil types.

The seed of the non-indigenous barren brome appeared to emerge more than the indigenous stock following tined cultivation only in the autumn in which they were spread on the surface. Levels of emergence of meadow brome were similar to barren brome each year at both Boxworth and Bridgets. Ploughing treatments were more effective than tine treatments in reducing emergence (below 5 per cent) at both sites; the greater depth of ploughing usually resulted in a reduction in emergence.

The levels of emergence of brome in both experiments were lower at Bridgets than at Boxworth. There were only very slight differences in the patterns of emergence at either site between the short and long dormancy stocks of winter barley. The proportion of seeds to emerge in the year of broadcasting the seed prior to the cultivation was greater with barley than brome and consistently greater at Boxworth than Bridgets with the tined cultivations.

INTRODUCTION

Brome grasses increased dramatically in the late 1980s, having been favoured by dry autumns in 1984 and 1985 (and to a lesser extent, in 1986) where germination was delayed (with little opportunity to kill the weed before drilling) well into the autumn so heavy infestations emerged with the crop. In the 1989 BCPC-funded survey of brome grasses 44% of crops in England and Wales were found to have brome grasses as weeds in the field centres and headlands (Cussans *et al*, 1992). The distribution of the bromes was very strongly biased towards the field margins and headlands (29%) although 12% of field centres were infested which would amount to 600,000 hectares in the UK as a whole.

Early work indicated that seeds of *Bromus* species had little dormancy, short persistence in the soil and were unable to emerge when ploughed in to deeper than 12 cm. Therefore, these species should have persisted only in a very specific husbandry system; where continuous, early-sown winter cereals were established without mouldboard ploughing. However, there were an increasing number of reports of field behaviour which did not fit into this predicted pattern; protracted germination, survival from mouldboard ploughing and survival beyond one year without seed production. These specific reports were linked with a general belief that these species were increasing in severity despite an increase in the use of mouldboard ploughing, which would have been expected to have the reverse effect.

OBJECTIVE

To determine the effect on seed viability of barren brome, meadow brome and volunteer cereals (particularly winter barley) of different types when tined cultivation or ploughing at various depths were used over a three year period on two contrasting soil types.

METHODS

The two experiments were started in September 1988, each with a site at ADAS Boxworth and ADAS Bridgets. The soil texture at Boxworth is a calcareous silty clay loam and at Bridgets a calcareous medium silty loam. Both experiments were sited on areas free from brome grasses or volunteer barley.

Experiment 1 - Effect of depth of cultivation

Various cultivation treatments were carried out on the same plots each year.

Cultivation treatments:
Tine cultivation to 5 cm (not possible at Bridgets EHF)
Tine cultivation to 10 cm
Tine cultivation to 15 cm
Plough to 15 cm
Plough to 20 cm

Weed species:
Indigenous barren brome.
Non-indigenous barren brome from Long Ashton Research Station (Boxworth only).
Short dormancy winter barley stock (Magie 8047) supplied by ESCA.
Long dormancy winter barley stock (Magie 8049) supplied by ESCA.
Meadow brome from ADAS Boxworth.

Seed of the brome grasses was collected from standing crops in July/August 1988.

The "weed" treatments were applied onto the soil surface immediately prior to primary cultivation in the first year at a rate of 10,000 seeds/square metre for brome and 250 seeds/square metre for barley. The crop and weed were removed the following summer and so the return of shed viable seed was prevented.

The experimental design was three randomised replicates with cultivation treatments on whole plots and weed species on sub-plots. Whole plots measured 20 m x 17 m and sub-plots 4 m x 2 m. The discard between sub-plots was 2 m - 9 m.

All cultivations were done along the length of the plots. At Boxworth the tine cultivations to 5 cm and 10 cm were done with a Flexitine and to 15 cm with a Soil-Saver which is a combined disc and heavy tine implement. Tine cultivation treatments were done at Bridgets with a light pigtail tined implement.

Straw of the previous crops was burnt each year except in June 1989 when both sites were mown and the material was removed by baling at Boxworth and by picking-up with a forage harvester at Bridgets.

The primary cultivation treatments were done at Boxworth on 27-29 September 1988, 8 September 1989 and 11 September 1990 and drilled on 7 October, 3 November and 11 October respectively. All treatments were rotary harrowed and rolled before drilling each year. The ploughed treatments in autumns 1988 and 1989 had extra secondary cultivation treatments. At Bridgets the primary cultivations were on 11 October 1988, 21 August 1989 and 13 September 1990 and drilled on 16 October, 12 October and 26 March respectively.

The seedrates were 170-180 kg per ha for spring and winter wheat and row width was 12.5 cm at both farms.

Glyphosate as Roundup was applied pre-harvest in 1988 and 1990, and to the stubble in July 1989 following the early removal of the crop and weed material. The trial areas were harvested with a combine harvester along the length of the plots in 1990 and 1991 and the straw was burnt. In 1989 the crop and weeds were removed at an early stage to prevent seed return.

Fertiliser application and crop protection against broad-leaved weeds, disease and pests were in accordance with good farm practice.

Assessments at Boxworth of plant numbers from which percentage germination was calculated were done using four quadrats per plot measuring 0.15 m x 0.15 m in autumn 1988 and subsequently all plants were counted in the whole of each sub-plot. Assessments at Bridgets were done in each plot on two fixed quadrats measuring 0.3 m x 0.3 m. In 1990 and 1991 the panicle number per plant was counted as each plant was hand rogued when the bromes were at the early panicle development stage.

Experiment 2 - Effect of depth of burial and time on seed viability

Seed in soil in trays was buried at specific depths in October 1988 at Boxworth and Bridgets.

Depth of seed buried:

5 cm

10 cm

15 cm

20 cm

Seed stocks buried:

Indigenous barren brome.

Non-indigenous barren brome from Long Ashton Research Station.

Length of burial:

Trays were lifted in autumn 1989 and autumn 1990, i.e. seed was buried 12 and 24 months.

Soil from each site was placed in the trays to a depth of 5 cm. Seed broadcast on top of this layer of soil was covered with a further 1.5 cm depth of soil to make it level with the top of the tray. The trays were then placed in pits so that the seed was at the appropriate depth when covered with more soil from the site. After excavation the soil above the seed was levelled off to the top of the trays.

There were three randomised blocks with each plot consisting of a tray measuring 0.56 m x 0.36 m containing 2000 seeds (10,000 seeds per square metre). The discard area between the trays was 20 cm or 30 cm. The trays lifted in 1989 and 1990 were placed outside at Boxworth.

Assessments of plant numbers per tray remaining buried were done at the early development stage of brome panicles each year. Plant counts on the lifted trays were done on a per tray basis on four occasions in the period November 1989 - April 1990 and on three occasions in November 1990 - June 1991.

The straw of the previous crop was burnt each year and winter wheat crops were established by direct drilling across the plots. Glyphosate as Roundup was applied pre-harvest and the area was harvested with a combine harvester.

Fertiliser applications and crop protection against broad-leaved weeds, diseases and pests were in accordance with good farm practice.

RESULTS

Experiment 1 (Tables C1 & C2)

The very large flush of brome plants at both sites in the autumn in which seed was broadcast (1988), particularly with the tine cultivation treatments, was an impediment to the assessment in November. Following tillering the weeds became so abundant, tangled and lodged that a further assessment could not be made in that cropping year and the crops were mown and removed without harvesting the wheat.

The assessment at Boxworth in October 1989 was between the cultivation treatments being applied and drilling the winter wheat crop. Emergence of the bromes and barley following drilling of wheat in autumn 1989 and 1990 was so low that assessments were delayed until the following June in both years.

No plants of brome or barley had emerged at Bridgets between cultivation and drilling in autumn 1989. Only very low levels of barley and no brome were found when the site was assessed on 21 February 1990 and very few brome plants were present in July of that year. A stale seedbed produced in autumn 1990 encouraged a few brome seeds to germinate by January 1991 but no additional weeds were evident prior to sowing spring wheat in March 1991. Very low levels of both brome species were recorded in June 1991.

Experiment 2 (Tables C3 & C4)

A very low proportion of seeds of both stocks of barren brome emerged from 5 cm depth and none from a greater depth in the 12 months after sowing. Less than 0.15 per cent emergence from each depth occurred in the two years after lifting the trays which had been buried for one year, or in the first year from trays buried for two years.

Emergence in the first year after burial was less than 0.05 per cent from 5 cm depth and nil from the greater depths. In the subsequent year of the trays buried for two years there was no further emergence. Following lifting less than 0.1 per cent emergence occurred in the next one or two years from trays buried for two or one year respectively.

DISCUSSION

Differences in levels of emergence of seed on the soil surface have been found between populations of barren brome (Peters, 1990). The seed of the non-indigenous barren brome appeared to emerge more than the indigenous stock following tined cultivation only in the autumn in which they were spread on the surface; no differences were apparent in the two subsequent years (Table C1). Levels of emergence of meadow brome were similar to barren brome each year at both Boxworth and Bridgets (Tables C1 & C2). The level of emergence of the brome stocks with tine cultivations at various depths in the first autumn (1988) was 26-44 per cent at Boxworth and 21-29 per cent at Bridgets. There was no consistency in the differences in emergence with the different depths of tine cultivation. However, both ploughing treatments were more effective in reducing emergence (below 5 per cent) at both sites; the greater depth of ploughing usually resulted in a reduction in emergence. Levels of emergence in the two subsequent years were less than 0.05 per cent with tine cultivations and nearly always zero with ploughing at Boxworth and less than 0.2 per cent and 0.1 per cent with tines and ploughing respectively at Bridgets.

In Experiment 2 the seed was placed at different depths whereas in Experiment 1 the cultivations would have dispersed the seed within the profile to the depth of the cultivation. Consequently levels of emergence from the shallowest depth of burial was less than two per cent at Boxworth and 0.03 per cent at Bridgets and there was no emergence of seed from the two stocks of barren brome from 10-20 cm depth at either site in the first or second year after burial.

The levels of emergence of brome in both experiments were lower at Bridgets than at Boxworth. In experiment 2 the level of emergence of barren brome in the second year of burial was 0.3 per cent or less at Boxworth and zero at Bridgets, indicating that most of the loss of seed (about 98 per cent) occurred in the first year. Although 2 per cent emergence may seem small, it could allow reinfestation to take place.

There were only very slight differences in the patterns of emergence at either site between the short and long dormancy stocks of winter barley. The proportion of seeds to emerge in the year of broadcasting the seed prior to the cultivation was greater with barley than brome and consistently greater at Boxworth than Bridgets with the tined cultivations. There was a trend for a reduction in emergence with each increment in the depth of tine cultivation at Boxworth but not at Bridgets. The level of emergence of barley in the subsequent years was less than with brome even where the seed was ploughed up again.

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Table 1C. Percentage emergence of seeds sown in autumn 1988, Boxworth.

Weed species and cultivation	Nov. 1988	Oct. 1989	June 1990	June 1991	Total
	Month of assessment				
Indigenous barren brome					
Tine, 5 cm	29.6	0.04	<0.01	<0.01	29.64
Tine, 10 cm	35.8	0.02	<0.01	0	35.82
Tine, 15 cm	26.5	0.02	<0.01	0	26.51
Plough, 15 cm	3.6	0	0	0	3.60
Plough, 20 cm	0.9	0	0	0	0.90
Non-indigenous barren brome					
Tine, 5 cm	44.1	<0.01	0	<0.01	44.10
Tine, 10 cm	42.8	<0.01	0	0	42.80
Tine, 15 cm	42.9	0	0	<0.01	42.90
Plough, 15 cm	0.8	0	0	0	0.80
Plough, 20 cm	1.2	0	0	0	1.20
Meadow brome					
Tine, 5 cm	34.4	0.01	<0.01	<0.01	34.41
Tine, 10 cm	33.9	0.01	0	<0.01	33.91
Tine, 15 cm	30.4	0.01	<0.01	<0.01	30.41
Plough, 15 cm	5.1	0	0	<0.01	5.10
Plough, 20 cm	2.8	0	0	0	2.80
Winter barley, Magie 8074					
Tine, 5 cm	99.0	0.06	0	0	99.06
Tine, 10 cm	81.2	0	0	0	81.20
Tine, 15 cm	76.8	0.01	0	0	76.81
Plough, 15 cm	0	0	0	0	0
Plough, 20 cm	0	0	0	0	0
Winter barley, Magie 8049					
Tine, 5 cm	98.8	0.04	0	0	98.84
Tine, 10 cm	78.8	0	0	0	78.80
Tine, 15 cm	63.2	0	0	0	63.20
Plough, 15 cm	14.4	0	0	0	14.40
Plough, 20 cm	4.4	0	0	0	4.40

NB. 10,000 brome seeds/m^2 and 250 barley seeds/m^2 were sown.

Table 2C. Percentage emergence of seeds sown in autumn 1988, Bridgets.

Weed species and and cultivation	Month of assessment Nov. 1988	Feb. 1990	Jul. 1990	Jan. 1991	Jun. 1991	Total
Indigenous barren brome						
Tine, 10 cm	29	0	<0.01	0.1	<0.01	29.10
Tine, 15 cm	21	0	<0.1	0.2	<0.01	21.20
Plough, 15 cm	4	0	0	0	0	4.00
Plough, 20 cm	1	0	<0.01	0	0	1.00
Meadow brome						
Tine, 10 cm	22	0	0	0.02	<0.01	22.02
Tine, 15 cm	26	0	<0.1	0.1	<0.01	26.10
Plough, 15 cm	3	0	<0.1	0	0	3.00
Plough, 20 cm	1	0	<0.01	0	0	1.00
Winter barley, Magie 8047						
Tine, 10 cm	44	0	0	0	0	44.00
Tine, 15 cm	52	0	0	0	0	52.00
Plough, 15 cm	13	<0.1	0	0	0	13.00
Plough, 20 cm	17	0	0	0	0	17.00
Winter barley, Magie 8049						
Tine, 10 cm	54	0	0	0	0	54.00
Tine, 15 cm	60	0	0	0	0	60.00
Plough, 15 cm	16	<0.1	0	0	0	16.00
Plough, 20 cm	5	0	0	0	0	5.00

NB. 10,000 brome seeds/m^2 and 250 barley seeds/m^2 were sown.

Experiment 2

Table C3. Percentage emergence of seeds (10,000/m^2) buried in autumn 1988, Boxworth

	Depth	Nov. 1988 *in situ*	Nov.-Apr. 1989 1990 after lifting	Nov.-Jun. 1990 1991 after lifting	Total
		Month of assessment			
<u>Buried one year</u>					
Indigenous barren brome	5 cm	1.92	0.02	0.03	1.97
	10 cm	0	0.05	0.02	0.07
	15 cm	0	0.03	0.10	0.13
	20 cm	0	0.05	0.08	0.13
Non-indigenous barren brome	5 cm	0.08	0.03	0.07	0.18
	10 cm	0	0.02	0.08	0.10
	15 cm	0	0.07	0.07	0.14
	20 cm	0	0.27	0.12	0.39
	Depth	Nov. 1988 *in situ*	Oct. 1989 *in situ*	Nov.-Jun. 1990 1991 after lifting	Total
<u>Buried two year</u>					
Indigenous barren brome	5 cm	1.68	0.18	0.08	1.94
	10 cm	0	0	0.05	0.05
	15 cm	0	0	0.02	0.02
	20 cm	0	0	0.13	0.13
Non-indigenous barren brome	5 cm	1.67	0.30	0.05	2.02
	10 cm	0	0.03	0.02	0.05
	15 cm	0	0	0.02	0.02
	20 cm	0	0	0.07	0.07

Table C4. Percentage emergence of seeds (10,000/m^2) buried in autumn 1988, Bridgets

	Depth	Month of assessment		
		Nov. 1988 *in situ*	Nov.-Apr. 1989 1990 after lifting	Nov.-Apr. 1990 1991 after lifting
<u>Buried one year</u>				
Indigenous barren brome	5 cm	0.03	0.08	0.03
	10 cm	0	0	0.03
	15 cm	0	0	0.05
	20 cm	0	0	0
Non-indigenous barren brome	5 cm	0.01	0	0
	10 cm	0	0.02	0.03
	15 cm	0	0.02	0.05
	20 cm	0	0.02	0.08
	Depth	Nov. 1988 *in situ*	Oct. 1989 *in situ*	Nov.-Jun. 1990 1991 after lifting
<u>Buried two year</u>				
Indigenous barren brome	5 cm	0.03	0	0.05
	10 cm	0	0	0.03
	15 cm	0	0	0.03
	20 cm	0	0	0.05
Non-indigenous barren brome	5 cm	0.01	0	0.03
	10 cm	0	0	0.03
	15 cm	0	0	0
	20 cm	0	0	0.05

PART D

VOLUNTEER CEREAL AND BROME GRASS CONTROL IN CEREALS

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ABSTRACT

A range of trials and surveys established in summer 1987 on the impact of cultural activities on barren brome and volunteer cereals were completed. Trials have shown that barren brome in a light, well drained soil, may emerge from greater soil depth, and may persist for longer, than has hitherto been accepted. The trials have shown the difficulty in achieving good seed burial with the plough. However, ploughing is still beneficial, and a farm survey showed that ploughing, plus herbicide treatment, tended to restrict the weed to the field margin. However, the weed is continuing to infest new fields and is spreading in field margins even where controlled in the field.

Ploughing to depth assists in the control of volunteer cereals, but does not give full control. The survey indicated that barley appears as a volunteer in 77% of following crops a year after being buried by ploughing. Wheat does not seem to be as frequent a problem as a volunteer. There is a suggestion from a depth of sowing trial that, although emergence is high after initial cultivation, if the soil is uncultivated in future years then no further barley emerges. It is possible that some forms of annual cultivation may not reduce the volunteer problem. This requires further study.

INTRODUCTION

Barren brome (*Bromus sterilis*) has become a widespread problem in arable fields in south-east Scotland, as in much of arable Britain, with 80% of cereal fields in a recent survey in the Lothians reported as having the weed present. Some of the factors involved in the persistence and spread of this weed are examined in this study. There is increasing concern in the East of Scotland about the apparent increase in volunteer cereal contamination in cereal crops with consequences for malt, distilling and milling crops as well as seed crops. Trials and surveys examined the factors that lead to these problems.

OBJECTIVE

To study the effects of varying husbandry practices on the survival of cereal seed and brome grasses by field trials and by assessment of infestations of cereal crops.

METHODS

The following elements of the project have been pursued over the study period:

1. The evaluation, by head-count assessment, of the survival of volunteer winter barley and barren brome at The Scottish Agricultural College - Edinburgh (formerly East of Scotland College of Agriculture) strategic, long-term cultivation site.

2. Evaluation by head-count assessment, of the survival of volunteer barley following a trial on a wide range of cultivation regimes, including straw incorporation, at a Scottish Centre for Agricultural Engineering (SCAE) site.

3. The identification of fields with barren brome and volunteer cereal problems, and an assessment of the populations and patterns of development of the infestations over the period of the project.

4. Four plot trials were established in autumn 1988 at the Bush Estate, on sandy loam soil, to look in more detail at the effect of cultivation, and the impact of depth of burial, on barren brome and volunteer barley survival. Two stocks of barren brome

(ADAS Boxworth and Long Ashton Research Station) and two batches of winter barley cv Magie, numbered 74 (20% dormancy) and 49 (10% dormancy) were used. In the cultivation x depth trials, seed was scattered over the soil surface prior to primary cultivation in autumn 1988. In the depth of burial trials, seed was buried at various depths and covered with soil in autumn 1988. Barren brome was sown at 10,000 seeds/m^2 and barley at 250 seeds/m^2. Techniques used and core design were linked with ADAS (91/1/87) and IACR Long Ashton (LARS - 93/1/87) trials (Parts C & E). Assessment was then made of weed emergence during the following autumn/winter. Cultivations were repeated annually for three seasons.

RESULTS

1. Long-term cultivation trials

Barren brome (Table D1)

Conventional ploughing substantially reduced brome populations in the winter barley crop in 1988, but did not eradicate the high populations of this weed. The brome was hand-weeded out of the plots before shedding in summer 1988 and this may have resulted in the very low populations in the following winter oilseed crop (1988/9). The population has remained at a constantly low level in succeeding winter barley crops; probably in part due to routine isoproturon-based autumn herbicide treatments. However, severe patches were still evident in direct drilled plots, although overall populations are low compared with earlier seasons. The weed was almost eradicated, however, from ploughed plots, and even rotovated plots, by the control programme.

Volunteer barley (Table D2)

Volunteer barley (six-row) was assessed in two-row winter barley in 1988 and winter oilseed rape in 1989 at the long-term cultivation site.

Conventional ploughing substantially reduced the volunteer barley population compared with other cultivation treatments, although all treatments reduced the population between the 1987/8 and 1988/9 crops.

2. SCAE straw and stubble cultivation trial

In the SCAE cultivations trial, burying straw and stubble to 20 cm gave the most effective control of a very high level of volunteer barley (Table D3). Follow-up surveys have not found any volunteer winter barley in spring barley crops sown in 1989 and 1990.

3. Survey results

Table D4 lists the crops recorded during the period of the survey and the weed problems examined. In some fields more than one of the surveyed weeds was present. Fields were selected as having a potential problem through SAC - Edinburgh's 'Adopt-a-Crop' system and through SAC Field Advisory Service.

Barren brome

In eight out of thirty fields surveyed, barren brome appeared for the first time in 1989 or 1990. It was not present in 1988, and farmers had not acknowledged its presence. In most cases the new recordings were on farms that already had barren brome recorded; but not in all cases. In five cases, the weed first appeared on the field margin alone. In all cases, the field margin had had herbicide treatment (usually glyphosate) to control weeds within 1-3 years. This is indicative of the rapid spread of barren brome in the east of Scotland, and indicates the importance of the impact of field margin vegetation management on its spread.

Barren brome was usually confined to the field margins in winter oilseed rape, potatoes, peas, carrots and spring cereals. A few flowering barren brome plants have been seen in one crop of spring barley and one of spring oats out of seven spring cereals crops examined over the project period. One winter oilseed rape crop was badly affected, but that was the only such crop that had had no herbicide treatment.

In general terms, presence of barren brome was restricted to field margins by the inclusion of a spring crop in the rotation. However, it is not eliminated from the field and the field margin infestation can re-infest the field.

All fields were ploughed routinely, with claims of plough depths of 7-11 inches (18-27 cms). The claims could not be substantiated, nor could the degree of inversion. However, farmers who had a potentially serious brome problem did claim to try to invert the soil. This was not always easy and in one case where weed and brome levels were severe the farmer admitted that inversion was almost impossible in that field in wet, heavy soil (field 1, Table D4).

In a number of cases farmers were recognising the problem and were using herbicides with cultivations to achieve control. Fields 15, 16, 17, 18, 20, 21, 22 and 30 had received isoproturon-based treatments (autumn post-emergence), fields 8 and 9 had had metoxuron (autumn post-emergence) and fields 5 and 6 had had tri-allate (pre-emergence). By 1990, the brome was restricted to the field margin in six of these twelve fields, and headland populations had dropped markedly in the rest.

Few of the fields visited had potentially serious levels of brome in the main field area within the headland. This confirms other survey results (Davies, 1990) for the region.

Barren brome infestations in field margins tended to spread over the period of the survey; both along the hedge or fence-line and into the field. Patches in headlands were more variable and could not be followed from season to season because of changes in cropping and chemical use.

Volunteer barley

The fate of volunteers from barley sown/harvested before 1987 and appearing in crops in 1988 and thereafter was examined in nine fields. However, by 1990 it was evident that volunteer barley had appeared in a number of other fields, being examined for other weeds, from barley seed shed in the 1987/8 harvest year.

Volunteer winter barley from eight out of ten crops recorded for barren brome infestations in 1988 was seen in 1990 harvested crops. Volunteer spring barley from two out of three 1988 crops recorded was seen in 1990 crops. Barley volunteers were thus seen to survive after one season of burial into following crops on about 77% of occasions.

Three recordings of volunteer barley were made in 1990 where the original seed source may have been sown in 1985. There is a possibility that volunteers had re-seeded during this period.

Volunteer wheat

There were relatively few incidenceS of volunteer wheat noted. It was recorded at four sites in 1988 but these sites had wheat in 1990 and the original volunteerS could not be distinguished from the sown crop. However, at two fields, winter wheat sown/harvested in 1987/8 was seen in spring barley in 1990. So, it is evidently capable of survival over a season and half in a ploughing regime.

Volunteer oats

Winter oats sown in 1985 were found in winter wheat in 1988, but not thereafter in winter wheat or spring barley (field 57).

Spring oats sown in 1986 were found in two fields of spring barley in 1988, but not thereafter in winter crops in one field and peas and wheat in a second field (fields 55 and 56).

Straw and stubble disposal

There were no clear effects from the method of straw and stubble disposal on barren brome populations. But poor records were kept by farmers of time of ploughing after harvest.

Winter wheat straw was generally chopped and buried whilst winter barley was mainly baled for animal use. It is not clear whether either practice had an effect.

4. Cultivation and sowing depth trials

Sowing depth - Barren brome

Table D6 gives the barren brome populations in seasons 1988/9, 1989/90 and 1990/1 from seed samples sown at 10,000 seeds/m^2 in autumn 1988 at a range of depths, with no further cultivations.

It is evident that sowing depth is a major factor in determining emergence of the weed, but a significant proportion of the seed sown (1-2%) emerged from 20 cm depth in 1988/9.

A few seeds survived to emerge in the following season (1989/90). Only seeds sown at 5-10 cm depth emerged, and not from below. No further emergence was seen in 1990/1. Soil samples were taken for seed viability tests by Long Ashton

Research Station in seasons 1989/90 and 1990/1. Those results are reported within project 0093/3/87 (Part E).

A larger proportion of the Boxworth seed sample emerged than the IACR Long Ashton (LARS) sample. A few seeds from both samples survived into the second season.

Sowing depth - Volunteer winter barley

Although a large number of plants emerged from both barley samples in the first season after sowing (Table D7), no plants emerged in the following seasons.

Increased sowing depth had a significant effect on reducing plant emergence. However, plants did emerge from the 20 cms sowing depth.

Cultivation - Barren brome

Ploughing clearly reduced barren brome emergence (Table D8) compared with tine cultivation, but a significant proportion still emerged from 15-20 cm depth. It was evident that in attempting to plough down seed, the seed smeared up the plough profile, so inversion was not accomplished.

Re-ploughing and tining in 1989 reduced populations further (particularly ploughing), but there was some survival into the 1989/90 season. There may have been some seed production from 1988/90 season plants despite use of paraquat and burning to prevent re-seeding.

Further destruction of plants from 1989/90 season helped reduce the population of brome to virtually zero following re-ploughing and tining in autumn 1990. A couple of plants emerged following tining to 15 cms.

Cultivation - Volunteer winter barley

Ploughing slightly reduced barley plant emergence compared with tine cultivation (Table D9) in first season after sowing.

A small number of plants emerged in the second year with a slight tendency to ploughing encouraging emergence over tine cultivation, unless tining was deep (15 cms). Very few barley plants emerged in 1990/1 season.

There was little or no difference between the cereal seed batches.

DISCUSSION

Barren Brome

* The results of the plot trials at Bush were surprising given earlier results on longevity and germination depth of barren brome (Froud-Williams, 1981). There is evidence of a small proportion (1-2%) of the seed emerging from 20 cms depth, and a very small proportion (<0.1%) persisting into a second season in undisturbed soil. Ploughing is certainly beneficial compared with tine cultivation, but did not give the control expected. The soil at Bush, where these sowing depth tests were done is relatively light and well drained, which may allow emergence from greater depth.

* An important factor noted whilst undertaking the trials is the difficulty in getting ideal soil inversion and it was evident that a smearing of seeds occurred up the plough profile as the soil was turned-over. This may be one of the main reasons for the often apparent poor performance of deep ploughing in cropping situations, as indicated in the survey; in particular in headland situations where the brome infestations are usually at their highest.

* However, the survey did indicate that ploughing with herbicide treatment did help to restrict the weed to the field margin.

* Spring cropping also helped restrict the weed to the field margin, although the occasional flowering plant was seen in spring cereals.

* The other reason for the persistence of the weed is the unsuspected, although very low, proportion of the brome seed-bank that does survive for longer than a season to re-infest future crops. Although the numbers surviving are very small, the ability of brome to produce large numbers of fertile seed would allow populations to build up quickly again. This reinforces the importance of continuing a herbicide strategy with the cultivation strategy for long-term control.

* Nevertheless, the survey indicates that the weed is still spreading with eight of the thirty fields with barren brome being infested during the three year project period. This reflects the importance of the weed in the region as noted in British Crop Protection Council-funded survey in 1989 (Cussans *et al.*, 1992). In most cases the weed first appeared in the field margin, although occasionally within the field. These field margins are usually devoid of a large range of species because of routine herbicide use. This is a classic situation for the ingress of weeds such as barren brome.

* Barren brome is tending also to spread along field margins, then, where cultivation and cropping permit, into the field crop. Even where the weed has been brought under control in the field by cultivation and herbicide use, or by changes in cropping, it remains in the field margin ready to re-infest when the opportunity arises. Long-term control also requires a method of controlling and managing vegetation in the field margin to prevent its establishment and spread.

Volunteer cereals

* The importance of cultivation is control of volunteer cereals was emphasised by the winter barley stubble cultivating trial at SCAE, and in the long-term cultivation trial at Bush. The SCAE site also showed the best effect was achieved from deep cultivation of straw and stubble. Unfortunately, this site was put into spring barley

for each of the following two seasons, and there were no volunteer winter barley plants seen. The plot trials at Bush showed the benefit of putting the barley seed deep, and ploughing to depth assisted keeping numbers down. However, some plants emerged from deep ploughing at all sites.

* The importance of future cultivation policy was emphasised by the large number of occasions noted in the surveys when winter barley, in particular, was evident in the second season after being ploughed-down. In about 77% of fields where barley was sown, it appeared as a volunteer after being ploughed back up. There was no follow-up cultivation in the sowing depth trial at Bush, and no barley plants emerged in second and third seasons. This emphasises the need for re-cultivation to stimulate further cereal emergence.

* Eventually, however, on the ploughed fields in the survey, and the trial plots, annual cultivation reduced the volunteer population diminished substantially.

* None of the fields in the survey were minimally cultivated in seasons following the initial ploughed-in barley crop. It would be of interest whether after deep ploughing of the cereal straw and stubble, the use of a year or two years of minimal cultivation would reduce the impact of the volunteer barley when the field was re-ploughed. This technique may assist in reducing problems where several volunteer populations are expected after a poor harvest with high grain losses.

* The survey also indicated that barley is more often a volunteer problem than wheat. Wheat volunteers were relatively infrequently seen.

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Table D1. Barren brome levels under different cultivation regimes: Bush Estate long-term site (no. plants/sq m)

	1987/8 W. Barley	1988/9 W. OS Rape	1989/90 W. Barley	1990/91 W. Barley
DD since 1968	59.7	0.9	1.41	0.44
DD since 1984	11.9	0.8	0.31	0.16
Ploughing	2.5	0.0	0.03	0.0
Rotovation	43.5	0.6	0.06	0.0

(DD = Direct Drilled)

Table D2. Volunteer barley levels under differing cultivation regimes: Bush Estate long-term site (No. plants/m^2)

	1987/8 Winter Barley Crop	1988/9 Winter Oilseed Rape Crop
DD since 1984	313.0	50.8
DD since 1968	363.2	67.8
Conventional plough*	70.0	3.1
Rotovation*	360.0	64.9

(DD = direct drilled)

The six-row barley was not assessed in the 1989/90 barley crop.

Table D3. Volunteer barley under differing cultivation regimes, SCAE; 1987/8 Winter Barley crop (mean results)

	No. Vol barley m^2
Straw + stubble; ploughed 20 cm	262.5
Straw + stubble; SCAE incorporator	815.0
Stubble; ploughed 10 cm	552.5
Straw + stubble; ploughed 10 cm	905.0
Stubble; tined 10 cm	1090.0
Straw + stubble; tined 10 cm	920.0
Stubble; rotovated 7 cm	737.5
Straw + stubble; rotovated 7 cm	825.0
Stubble; rotovated after sowing	702.5
Straw + stubble; rotovated after sowing	555.0

Table D4. Recording of barren brome and volunteer cereal populations

		Crop Recorded/Year		
		1988	1989	1990
Infestation*				
Barren brome	1	WB	WOSR (none)	WW
	2	WW (none)	WW (none)	WW+
	3	WW	WW	WOSR (hedge) -
	4	WW (none)	WW +	WW
	5	WW	WOSR (hedge)	WW
	6	WB	WOSR (hedge)	WW
	7	WB	WOSR	WOSR
	8	WW	WW	WW
	9	WW	WW	WW
	10	WW	WW	WW (none)
	11	WW	WW	WW
	12	WW	WW	Potatoes (hedge)
	13	WW	WW	WW
	14	WW	SB	Potatoes (hedge)
	15	WW	WW (hedge)	Potatoes (hedge)
	16	Potatoes (none)	WW (hedge)+	WW (hedge)
	17	Potatoes (none)	SW (hedge) +	WW(hedge)
	18	WW	WW	WW (hedge)
	19	WW	WW	SB (hedge)
	20	WW (none)	WW (hedge)	WW (hedge)
	21	WW (none)	WW (hedge) +	WW (hedge)
	22	WW (hedge)	WW (hedge)	WW (hedge)
	23	SB (none)	Potato (none)	WW (hedge) +
	24	WW	WW	WW (hedge)
	25	WW	SO	SB (hedge)
	26	WB (none)	WOSR (none)	WW
	27	WW	Carrots (none)	Potatoes (none)
	28	WB	WOSR (none)	WOSR (none)
	29	Peas (hedge)	WW	SB (hedge)
	30	WW (hedge)	WW (none)	WW (hedge)

(+ New Recording)

Table D4 (Contd). Recording of barren brome and volunteer cereal populations

Infestation*		Crop Recorded/Year 1988	1989	1990	Year sown
Winter Barley	31	WW	SB (none)	SB (none)	1984/5
	32	WW	SB (none)	SB (none)	1985
	33	WB	WOSR (none)	WW	1987
	34	WW	WW (none)	WW	1987
	35	WW	WW	WW	1985
	36	WW	WOSR (none)	WW	1985
	37	WB	WOSR (none)	WW	1985
	38	WW	SB	Grass (none)	1987
	39	WB	WOSR (none)	WW	1987
	40	WB	WOSR (none)	WW	1987
	41	WB	WOSR (none)	WW	1987
	42	WB	WOSR (none)	WW	1987
	43	WW	WW	SB (none)	1985
	44	WB	WOSR (none)	WW	1987
	45	WW	SO	SB (none)	1985
	46	WW	Calabrese (none)	WW	1985
	47	WW	WB(?)	Peas (none)	1985
Winter Wheat	48	WB	WOSR (none)	WW (?)	1985
	49	WB	WOSR (none)	WW (?)	1985
	50	WB	WOSR (none)	WW (?)	1985
	51	WW (none)	WW (?)	SB	1987
	52	WW (none)	SO (none)	SB	1987
	53	WB	Fodder beet (none)	WW (?)	1987
Spring Barley	54	SB	Peas (none)	WW	1988
	55	SB	WOSR (none)	WW	1988
Spring Oats	55	SB	WOSR (none)	WW (none)	1986
	56	SB	Peas (none)	WW (none)	1986
Winter Oats	57	WW	WW (none)	SB (none)	1985

*Infestation present unless otherwise stated. (?) Same species; untrue of volunteer status. WW: winter wheat; WB: winter barley; SB: spring barley; SO: spring oats; WO: winter oats; WOSR: winter oilseed rape.
Hedge: only in field boundary.
Year sown: presumed origin of infestation.

Table D5. Population changes in barren brome 1988-90 survey

Field (cropping)	Area*	Mean No. plants/m^2 (m into field) 1988	1989	1990
1 (WB/OSR/WW)	M	(0.3-4)	-	(0.3-4)
	H	17.4	-	84.2
	F	0.7	-	0
2 (WW/WW/WW)	M	0	0	(0.5-1)
	H	0	0	0.2
	F	0	0	0
3 (WW/WW/OSR)	M	(0.3-1.3)	(0.3-2)	(0.3-2)
	H	1.0	1.1	-
	F	0.1	0.1	-
4 (WW/WW/WW)	M	(0)	(0.3)	(0.3-1)
	H	0	0.1	0
	F	0	0	0
5 (WB/OSR/WW)	M	(1-3)	(1-3)	(0.3-1.5)
	H	4.2	-	A+0
	F	0	-	A+0
6 (WB/OSR/WW)	M	(0.1-1.3)	(0.1-1.5)	(0.3-1.5)
	H	1.64	-	A+0.24
	F	0	-	A+0.1
7 (WB/OSR/OSR)	M	(1-6)	(1-8)	(1-20+)
	H	39.0	-	>100
	F	0.3	-	>100
8 (WW/WW/WW)	M	(0.3-5)	(0.8-1.5)	(0.3-1)
	H	6.9	D+0.9	0
	F	Trace	0	0
9 (WW/WW/WW)	M	(2-12)	(1-3)	(0.3-2)
	H	31.7	D+26.4	D+0.1
	F	-	-	-
10 (WW/WB/WW)	M	(0.1-2)	(0.03)	(0.3-1)
	H	0.5	D+0	0
	F	0	0	0
11 (WW/WW/WW)	M	(0-3)	(2-3)	(0.0.3)
	H	0.55	D+0.1	0
	F	0	0	0
12 (WW/WW/Pot)	M	(1-2.5)	(0.3-3)	(0.5-1)
	H	2.4	0.11	0
	F	0.04	0	0
13 (WW/WW/WW)	M	(0.3)	(0.2-0.8)	(1-2)
	H	0.5	I+0	0
	F	0	0	0
14 (WW/SB/Pot)	M	(1-2.8)	(0.3)	(0.3)
	H	0.32	0	0
	F	0 Trace	0.04	0

Table D5 (Contd). Population changes in barren brome 1988-90 survey

Field (cropping)	Area*	Mean No. plants/m^2 (m into field)		
		1988	1989	1990
15(WW/WW/Pot)	M	(0.5-1)	(0.2)	(0.3)
	H	1.8	I+0	0
	F	0	0	0
16 (Pot/WW/WW)	M	(0)	(0.3-0.5)	(0.5-1.5)
	H	0	0	0
	F	0	0	0
17 (Pot/WW/WW)	M	(0)	(0-1)	(0.5-2.5)
	H	0	0	0
	F	0	0	0
18 (WW/WW/WW)	M	(0.8-1.8)	(0.3-4)	(1-3)
	H	0.6	I+0.4	I+0
	F	0	0	0
19 (WW/WW/SB)	M	(1-10)	(1-20)	(0.5)
	H	23.2	I+2.4	0
	F	0	1.6	0
20 (WW/WW/WW)	M	(0)	0	(0.3-0.5)
	H	0	0.1	I+0
	F	0	0.3	0
21 (WW/WW/WW)	M	(0)	(0-1)	(0-1)
	H	0	0	0
	F	0	0	0
22 (WW/WW/WW)	M	(0-1)	(2-3)	(0.5-1)
	H	0	0	0.2
	F	0	0	0
23 (SB/Pot/WW)	M	(0)	(0)	(0.3)
	H	0	0	0
	F	0	0	0
24 (WW/WW/WW)	M	(0.5-3)	(0.3-1)	(0.3-2)
	H	0.6	I+0.4	I+0
	F	0	0	0
25 (WW/SO/SB)	M	(0.3-2)	(1-2)	(2)
	H	Trace	1.4	0
	F	0	0	0
26 (WB/OSR/WW)	M	(0)	(0)	(0-1)
	H	0	0	0
	F	0	0	0
27 (WW/Car/Pot)	M	(0-3.5)	(0-1)	(0-0.8)
	H	1.5	0	0
	F	0	0	0
28 (WB/OSR/OSR)	M	(0)	0	0
	H	0.2 first	0	0
	F	0.3 year	0	0
29 (Pea/WW/SB)	M	(0-2)	(0-2)	(0-2)
	H	0	0.04	0
	F	0	0	0

Table D5 (Contd). Population changes in barren brome 1988-90 survey

Field (cropping)	Area*	Mean No. plants/m² (m into field) 1988	1989	1990
30 (WW/WW/WW)	M	(0-03) First	(0.03)	(0-0.3)
	H	0.03 year	0	0
	F	0	0	0

Area : M = field margin; H = headland; F = main field
: A = tri-allate; D = metoxuron; I = isoproturon used for control; SB+ - spring barley headland
Crops: WW = winter wheat, WB = winter barley, SB = spring barley
SO = spring oat, Pot = potato, Car = carrot, OSR = winter oilseed rape

All scores are means; the weed is usually very patchy with high concentrations and crop areas with no weed.

Table D6. Effect of depth of sowing on barren brome seed emergence

Sample Sowing	Depth (cms)	Mean No. Barren Brome Plants/m² 1988/9	1989/90	1990/1
LARS	5	2133	6.4	0
LARS	10	467	3.1	0
LARS	15	233	0	0
LARS	20	167	0	0
BOXWORTH	5	3000	0	0
BOXWORTH	10	733	12.7	0
BOXWORTH	15	767	0	0
BOXWORTH	20	100	0	0
SED Seed (S)		209.2	0.95	-
Depth (D)		295.9	1.38	-
S x D		418.5	1.90	-

Table D7. Effect of depth of sowing on barley seed emergence

Sample Sowing	Depth (cms)	Mean No. Barley Plants/m^2 1988/9	1989/90	1990/1
74	5	1867	0	0
74	10	1267	0	0
74	15	867	0	0
74	20	200	0	0
49	5	2400	0	0
49	10	1367	0	0
49	15	633	0	0
49	20	333	0	0
SED	Seed (S)	145.5	-	-
	Depth (D)	205.8	-	-
	S x D	291.1	-	-

Table D8. Effect of annual cultivation on barren brome survival

Sample	Cultivation	Depth (cms)	Mean No. Barren Brome Plants/m^2 1988/9	1989/90	1990/1
LARS	PLOUGH	15	2100	0.3	0.0
LARS	PLOUGH	20	625	1.3	0.0
LARS	TINE	5	3538	14.3	0.0
LARS	TINE	10	3375	38.0	0.0
LARS	TINE	15	3513	10.0	0.3
Boxworth	PLOUGH	15	2088	3.0	0.0
Boxworth	PLOUGH	20	1375	1.8	0.0
Boxworth	TINE	5	3525	67.3	0.0
Boxworth	TINE	10	3425	50.8	0.0
Boxworth	TINE	15	3650	45.8	0.0
SED	Seed (S)		202.6	4.32	0.05
	Cultivation (C)		320.3	6.83	0.08
	S x C		453.0	9.66	0.11

Table D9. Effect of annual cultivation on barley survival

Sample	Cultivation	Depth (cms)	Mean No. Barley Plants/m^2 1988/9	1989/90	1990/1
74	PLOUGH	15	288	8.5	0
74	PLOUGH	20	213	14.5	0.3
74	TINE	5	438	2.3	0
74	TINE	10	350	0.3	0
74	TINE	15	375	7.0	0
49	PLOUGH	15	63	3.8	0
49	PLOUGH	20	150	7.5	0.3
49	TINE	5	338	1.5	0.3
49	TINE	10	513	1.0	0
49	TINE	15	500	4.5	0
SED	Seed (S)		37.7	1.41	0.09
	Depth (D)		59.6	2.23	0.14
	S x D		84.3	3.15	0.19

PART E

SEED DORMANCY AND LONGEVITY IN SOME BROME SPECIES AND CEREALS

N.C.B. Peters & H.A. Atkins, IACR Long Ashton

ABSTRACT

Seed from twenty four populations of *Bromus sterilis* were collected from 23 farms in Southern England and seed of each population was grown under the same conditions at Long Ashton and tested for germination behaviour. Laboratory tests of the freshly collected seed showed that only one farm had a population where there was some innate dormancy in the seed (31% germination after 105 days at 15°C in the dark).

However, there was a wide range in the capability of the populations to be enforced into dormancy by light (22% - 98% germination after 28 days at 15°C in 12 hrs dark 12 hrs light). The dormancy could be relieved by placing the seed in the dark.

Two farms had seed populations which could be induced into dormancy by light, which could not be relieved by placing the seed in darkness or 0.2 g/litre of KNO_3, but was relieved by 0.5 g/litre gibberellic acid (GA_3).

In micro-plot field experiments, freshly collected seed was sown on the soil surface at the beginning of August. By 23rd October, when most cereal drilling would have been done, there was between 4 - 10% of seed remaining ungerminated in low dormancy populations (including the Standard British Barren Brome Population [SBBBP]). However, 28 - 54% of the seed was left ungerminated in the higher dormancy populations. Clearly it would be more difficult to bury all the seed by ploughing where large numbers of seed remain ungerminated on the soil surface, and thus control by ploughing would be more difficult to achieve.

There can be large seasonal effects on the numbers of seed remaining ungerminated on the soil surface in the autumn, for it was found that in another year, with the same range of high dormancy populations, 57% - 85% of the seed sown on the surface could remain ungerminated by 23rd October. Only one of the same low dormancy populations was tested but 40% of the seed of this population remained ungerminated compared with 7% in the previous experiment.

Where seed of the SBBBP was kept moist on the soil surface from the time of shedding it speeded up germination, but it inhibited the germination of more dormant populations, compared with where seed of both populations received natural rainfall. However, this initial restriction of germination had no long-term effect on the decline of the populations. For, after a year on the soil surface, there was no significant difference between the number of viable seed surviving in the continuously moist, compared with the natural rainfall treatments in either the dormant or the less dormant populations.

Where seed of either the SBBBP or a more dormant population was either buried in sandy silty clay loam immediately after harvest or left on the soil surface before burial, it was found that timing of burial up to three months after placing the seed on the soil surface was not very important in determining the long-term survival of the seeds in the soil. However, when the same range of populations was exposed throughout the winter on the soil surface (i.e. exposed to light, moisture and low temperature) then recovered the following spring, it was found that all populations had been induced into dormancy. For, when placed in the dark seed germination was very slow. Burying such seed to determine if it can remain ungerminated in the soil for long periods has not yet been tested. However, the message at present is to bury the seeds as soon as possible after harvest to avoid any possibility of the seed being induced into dormancy and therefore having the potential for long-term survival in soil.

From experiments concerning the burial of *B. sterilis* seeds it can be concluded that burial of seed in the autumn to plough depth should result in all seed of the SBBBP dormancy level being lost from the lighter soil types within a year after burial.

However, small (0.06%) but important numbers of seed of more dormant populations have been found to survive at least one year in light soils and at least two years in heavy soils (0.06%). Indeed in heavy soils even the SBBBP has been found to survive at least two years (0.06%). Soil texture or other soil factors, rather than 'soil type' *per se*, may be responsible for the greater survival of seed in heavy soil. Although these percentages are small, when the initial population of seeds are large (20,000 seeds per m^2 from 100 plants) 0.06% represents 12 potential seedlings per m^2.

There has been considerable difficulty experimentally in detecting such small numbers of seeds after one to two years in the soil, but the mere fact that small numbers can be detected provides forceful evidence that there should be greater emphasis put on the potential for the longer term survival of *B. sterilis* populations, particularly those known to be easily induced or enforced into dormancy.

Detailed experiments on the development of viability of the seed in the heads of *B. sterilis* revealed that seed became viable within two to seven days after anthesis, and that all seed in the panicles were viable after 16 days. In set-a-side situations where cutting is the main form of control, it is necessary to cut the sward before the panicles contain viable seed. To allow for variability in developmental stages in the field, plants should be cut well before the anthesis stage. An appropriate stage which is easily recognisable would be when the panicles first became visible.

A pot trial in which the growth regulator 1-(3-chlorophthalimido) cyclohexanecarboxamide (AC94377) or gibberellic acid (GA_3) were applied to *B. sterilis* seed (dormant population) on the soil surface, showed that provided the seed was sprayed on the soil surface and then incorporated, 0.5 kg - 2.0 kg AI/ha of AC94377 gave 91 - 92% germination after 16 days compared with 88% in the GA_3 1000 ppm and 26% in the surfactant controls. Currently, there is no recommendation for the use of either AC94377 or GA_3. However, this method of control could offer an alternative control measure to replace stubble burning.

OBJECTIVES

To investigate the characteristics of seed populations of *Bromus* species which can lead to their long-term survival and germinability in the field.

INTRODUCTION

In the first year of this project a review of the seed biology literature on the various agronomically important brome grasses in the UK with special reference to *Bromus sterilis* was carried out.

The main conclusions from this review (HGCA Project Report No. 17) were that dormancy in *B. sterilis* seed could be enforced by light, drought and high temperature, but that there was little evidence of inducible dormancy which would have gone some way to explaining why some farmers were finding that some populations were more persistent than others.

Burial at 10 - 15 cms was regarded as the depth from which no emergence could occur, but at which germination could take place, thereby explaining the effectiveness of ploughing (to a depth of 10 - 15 cms) in controlling this weed.

However, all of the research had been done with relatively few populations of *B. sterilis* and very little research had been done on the survival of the seed under field conditions.

To investigate seed dormancy behaviour, 24 different populations were collected from Southern England and grown under common conditions at IACR Long Ashton, and experiments conducted on the germination behaviour of these populations.

In addition, selected populations were either left on the soil surface or buried to determine their longevity. The experiments were done in the contrasting soil types of IACR Long Ashton, ADAS Boxworth and at Bush Estate, Penicuik.

The report outlines the findings from these experiments.

LABORATORY TESTS OF DIFFERENT POPULATIONS

Methods

In 1988 in Southern England seed of 20 populations was collected from field centres and a further four from field margins. In 1989 each of these populations was grown at Long Ashton under common conditions and their seed collected between 4th and 17th July. Eight replicates of 50 seed of each population were set up in Petri dishes containing 1 glass fibre + 3 Whatman No. 1 filter papers with 8 ml distilled water were placed in either a 12 hr/12 hr light/dark regime or in continuous darkness at 15°C.

Germination was recorded at weekly intervals. After 15 weeks the light/dark treatment was placed in continuous darkness, and after 18 weeks the water was replaced with a solution containing 2.0 g/litre of KNO_3. After 22 weeks, to obtain the total viability of the seed in each dish, the KNO_3 solution was replaced with a solution containing 0.5 g/litre of gibberellic acid (GA_3). The experiment was terminated after 24 weeks.

Results

The results after 28 days of test are given in Fig. E1. By this date nearly all populations had germinated 100% in the dark, apart from two populations (34 and 35) which were collected from one farm. So, it would appear that there are only a few populations which have a large amount of INNATE dormancy. However, there was a wide range of germination both in the field margin and field centre populations in the amount of germination which occurred in the light/dark regime (overall range 22% to 98% germination after 28 days). Therefore, there is a considerable range between populations in the amount of dormancy which had been ENFORCED by light. After 15 weeks when the light/dark treatment was placed in darkness, the seed of all populations apart from nos. 34, 35 and 8 rapidly (within 2 weeks) achieved 100%

germination. The germination in population 35 was increased 1% from 31 to 32%. In population 34 germination was not increased, the total remaining at 25%, and in population 8, germination increased from 49% to 90%. Addition of KNO_3 solution did not promote the germination of the remaining seed and it was not until the gibberellic acid (a dormancy-breaking chemical) was added that germination of the remaining seed occurred. Therefore, for the first time there was clear evidence that some seed populations of *B. sterilis* have the capacity for INDUCED dormancy (two farms out of twenty-two).

Further analysis of the data was carried out by fitting a distribution of times to germination for each dish. Several distributions were tested and the one that was found to well describe the germination curve was Gompertz type distribution. This distribution was fitted using Genstat. From this analysis it is possible to obtain an estimate of the time it takes for 50% (T_{50}) of the estimated maximum number of seeds which would have germinated under continuing conditions. As can be seen from Table E1, the estimated maximum number was very similar to the actual total number of seeds which had germinated by 15 weeks, i.e. when the light/dark seeds were placed in the dark.

As all the populations apart from numbers 34, 35, 39 and 43 germinated to almost 100% in the dark in 7 days (i.e. at the time when the germination was first recorded), the analysis of this data is not included.

To simplify comparisons of the populations, means of the two parameters in Table E1 were sorted and the LSD used to find any clear groups of collections with similar behavioural characteristics.

In Table E2 only the total germination showed any grouping, with populations 34 and 35 forming a group and population 8 being significantly different from the rest. Further analysis of the T_{50} values against the total germination revealed that populations 34, 35, 8, 2 were significantly different from the rest, although there was a lot of variation between the collections when they were germinating in a dark/light diurnal regime. After 15 weeks the value of T_{50} ranged from 1 day to 32 days, and the value of the total percentage germination 25% - 100%.

Discussion

1. Only one farm out of 23 farms had a population which exhibited innate dormancy.

2. There was a wide range in the enforceable dormancy between populations. This could result in very much larger numbers of seed remaining on the soil surface on some farms compared with others.

3. In the populations from two farms out of 23 there was evidence of induced dormancy. This was the first time, that induction of dormancy in *B. sterilis* seed had been proven, although it had been previously suspected. Such populations would probably have the ability to survive ungerminated in soil for much longer periods than other populations, because once induced into dormancy by light the seed cannot germinate in darkness, e.g. if the seed was buried by ploughing after having been on the soil surface.

DETAILED OUTDOOR MICRO-PLOT EXPERIMENTS PRIMARILY CONCERNED WITH THE BEHAVIOUR OF SEED ON THE SOIL SURFACE BUT WITH SOME INVESTIGATIONS INTO SEED BURIAL

Experiment 1

<u>Methods</u>

Seeds of six populations of *B. sterilis* were collected between 4th-7th July, 1989, and four replicates of 1,000 seed of each population sown on the surface of small rectangular pots of soil 27 x 42 cms on 8th August, 1989. The populations were selected to span the range in the dormancy characteristics previously determined for this species. Counts of germination were made at weekly intervals, and the seed protected from birds and mice. Between 18th May and 10th June, 1990 all remaining seeds were exhumed and tested for viability.

Results

The results of this experiment are given as a series of germination curves, Fig. E2. The distribution of the times until germination was estimated for each dish and several distributions were tested for fitness. As in the laboratory germination tests the Gompertz-type distribution was fitted using Genstat. From this it is possible to obtain a value for the time to 50% of the total germination attained by each population (Table E3).

Clearly there is some overlap, but populations 34 and 39 are significantly different from 28, 29 and 40. Likewise from the same analysis a value for the maximum germination can be obtained (Table E4).

An analysis of variance of the total germination at the end of the experiment also showed the same groupings. There are therefore distinct differences in the germination behaviour of the different populations.

At the end of the experiment the number of seeds remaining viable but not germinated was also analysed using an analysis of variance. The data needed to be transformed using a square root transformation $\sqrt{(counts + 0.5)}$ to normalise the variance (Table E5).

The range in the percentage survival of viable seed in 18th May - 10th June, 1990 was therefore 1 - 36%. Clearly, some of the more dormant populations have a very good chance of surviving on the surface for at least a year after shedding, so non-cultivation for a year to rid the surface of seed is not an option.

Experiment 2

Methods

This experiment was set up in the same way as Experiment 1. Seeds were sown on 8th August, 1989 of two populations (Pop. 40, a standard low dormancy population collected 11th July and Pop. 50, a high dormancy population capable of induced dormancy, collected 6th July). The seed was subjected to four treatments.

1. Left on the surface to receive any natural rainfall.
2. Left on the surface and kept moist until buried in the autumn (20th October).
3. Left on the surface and kept moist until rain wetted up the soil surface in the autumn.
4. Buried at the start of the experiment.

Counts of the germination/emergence were made at weekly intervals and all remaining seeds in each treatment were exhumed and tested for viability between 18th - 25th July, 1990.

Results

The result of the germination/emergence behaviour is given in Fig. E3. The low dormancy population (40) when buried (dark) germinated to 100% almost immediately, whereas the more dormant population germinated at the same rate, but did not achieve such a high overall total germination (77% after 30 days). Left on the soil surface without additional water (rainfall sufficient to allow germination only fell once during the period before the autumn burial treatments) germination was slightly faster in the low dormancy population, and a greater number of seeds had germinated (probably due to the lower dormancy seeds being able to take greater advantage of the initial moisture present on the soil surface) than in the higher dormancy population. From mid-September onwards, natural rainfall allowed germination in the low dormancy non-watered treatment to catch up (end October) with the germination in the equivalent watered treatment. Likewise, when moisture became available to the high dormancy population on the dry soil surface, germination increased so that by 25th October, 65% germination had occurred. In comparison, in the surface treatment where the high dormancy seed had been kept moist from the time of sowing, only 48% had germinated by this time. Therefore, in a moist harvest/autumn it is likely low dormancy populations left on the soil surface will germinate rapidly, whereas if high dormancy populations are present, the rate of germination will be slowed down, so that a greater number of seed will be left on the soil surface by the time a farmer cultivates the land for autumn cereal planting.

Where the low dormancy seed had been kept wet before burial, by the time burial took place, the majority of the seed had germinated. Whereas, when the high dormancy wetted seed was buried, the germination increased up to the same level as that in the seed which was buried from the start (90%). Therefore, exposure of the high dormancy population on the wet soil surface for 43 days before burial had not altered the amount of germination a farmer could expect in the autumn, in comparison with where he may have buried the same seed immediately after harvest.

The number of viable seeds remaining at the end of the experiment are given in Table E6. The data need to be transformed before analysis as in the first experiment. Both the low dormancy (Pop. 40) and the high dormancy (Pop. 50) surface wet then buried, and the buried from the start treatments had virtually no viable seeds remaining and were excluded from the analysis. However, it must be said that 0.2% survival of the high dormancy seed that had been buried at the start of the experiment was recovered. This indicates that a small but important number of seeds (20 seed, if 10,000 seeds were originally shed) would survive almost twelve months in the soil, compared with none in less dormant populations.

No significant difference was found between the surface dry and surface wet treatments in a given population, but there were significant differences between the same treatments in the two populations. Therefore, although in the autumn there were greater numbers of seeds remaining in the more dormant population when it was kept moist from the start compared with where the seed was initially dry, by the following year, both treatments had almost equal remaining numbers of viable seed. Thus, initially moist conditions have short-term, but no long-term effects on the survival of dormant or indeed less dormant populations.

Experiment 3

Methods

The third experiment in this series was set up using the same technique as in Experiments 1 and 2. Seed was collected between 19th - 21st July, 1990 from six populations representing a wide range in dormancy behaviour. Four replicates of 500 seed of each population were sown on 10th August either (a) on the soil surface, (b) buried at 2.5 cms, or (c) sown on the soil surface and then buried on 8th November, 1990 (91 days after placement on the surface). Counts of germination were made at weekly/fortnightly intervals between 4th - 8th April, 1991 all remaining seeds were exhumed and tested for germinability and viability.

Results

In the buried treatment populations 39, 27, 40 and 41 all reached 95 - 100% germination after 20 days burial. Populations 34 and 35 also reached 95 - 100% germination but after 55 days, the two latter populations again proving themselves to be more dormant. Where the seeds were left on the surface for 91 days before burial, all populations had reached 90 - 97% germination 22 days after burial, so leaving the seed on the surface for that length of time (beginning of November) had not imposed dormancy on the seed, thereby slowing emergence.

An analysis of variance of the percentage seeds germinating by 25th October/26th October (i.e. just before burial) gave the following result (Table E7).

Seeds on the surface then buried treatment were only buried after 8th November, 1990, so the surface and surface/then buried treatments should have had similar levels of germination up to the time of the result in Table E7, and indeed there was no significant difference between them. For both treatments populations 34, 35 and 39 had significantly lower germination than the rest, and 34 and 35 were significantly lower than 39. This fits in with the relative order of dormancy in these populations found in other parts of this project.

Germination in the buried treatment did not vary significantly between treatments with all treatments having almost reached the maximum.

If the results of the first experiment in this section are compared with the results in the present experiment it can be seen that there are marked differences in the percent number of seed surviving viable but ungerminated by 23rd October in the two years (Table E8).

In the first experiment storage of the seed prior to sowing was slightly longer - approximately 4 weeks in Experiment 1 compared with 3 weeks in Experiment 3. There is therefore the possibility that this extra weeks dry storage may have reduced dormancy in Experiment 1. However, it would seem more likely that it was a difference in the climate between the two years either before or after shedding which caused the difference in dormancy level. Rainfall was similar during the period between sowing and 23rd October in each year, so this factor could be excluded as a main cause of the difference.

The % number of seeds germinating in each treatment at the time when the seeds were exhumed from each treatment on 4th April, 1990 is given in Table E9.

The buried and surface then buried treatments were not significantly different, indicating that the germination in the surface then buried treatment had caught up the germination in the buried at the start treatment. Only populations 34 and 35 had increased germination numbers in the buried treatment since 25th/26th October, and this increase was minute. Also, only populations 34 and 35 had ungerminated seed remaining at the end of the experiment, and all these seeds were found to be viable (Table E10).

The numbers in Table E10 are too small to compared statistically as they are likely to be affected by the small (max 6%) number of seeds lost during the experiment.

At the end of the experiment in the surface treatment, populations 34, 35 and 39 still had significantly lower germination than the rest. Tests of the viability of any remaining ungerminated seed showed it to be viable, and so the total germination in each population (Table E11) was similar except for population 34, in which there was a slightly greater loss in seed viability.

One of the major findings from this experiment is shown in Fig. E4, and shows the germination of the seed recovered from the soil surface in April 1990. The recovered seed was placed in Petri dishes as previously described and kept in the dark at 15°C. Under these conditions it was expected from previous findings that all the populations would germinate rapidly apart from populations 34 and 35. For, all the other populations had been shown to be able to be enforced into dormancy by light, whereas populations 34 and 35 can be induced into dormancy by light, and thus do not germinate readily in the dark after exposure to light. However, Fig. E4 shows that all populations germinated slowly. After 60 days the percentage germination of this recovered seed ranged between 18 - 59% across the populations. Nevertheless, when gibberellic acid (GA_3) at 500 ppm was applied, all the remaining ungerminated seed then germinated, showing that all the remaining seed was viable, and that all populations had been strongly induced into dormancy by the light/wet/cold present on the soil surface during the winter.

Discussion

1. From experiment 1, with the majority of populations including the SBBBP it was found that there can be between 1 and 5% of the initial seed shed left on the soil surface in May/June of the year after the year of shedding. With more dormant types which are restricted to a limited number of farms, the percentage surviving ungerminated can rise to 19 - 36%.

2. In the same experiment by 23rd October (in the year of shedding) there was between 4 and 10% in the three 'normal dormancy' populations including the SBBBP and between 28 and 54% in the three more dormant populations of the initial seed shed. If 10,000 seeds per m^2 are shed initially (from approx. 25 plants), these percentages represent 400 - 1,000 and 2,800 - 5,400 seeds per m^2 respectively. Clearly it will be more difficult to bury all the seed by ploughing where large numbers of seed are present.

3. In the third experiment which was done in a different year to experiment 1, there was a much greater survival of seed with time. With the same three dormant populations there was between 57 - 85% remaining ungerminated by 23rd October in the year of shedding. Only one of the same low dormancy populations was used, but this had a 40% survival by 23rd October compared with only 7% in the first experiment. Clearly there can be large differences in survivability between years. Climatic factors were suspected as being the cause of this variation.

4. A simulated wet autumn which kept seed moist from the time of shedding speeded up the germination of the 'normal dormancy' types including the SBBBP, but it inhibited the germination of more dormant populations. However, this initial restriction of germination had no long-term effect on the decline in number of seeds on the soil surface. After almost a year there was no significant difference in the numbers of seed in the initially wet and dry treatments.

5. In one experiment (1), after burial for 11 months, low numbers (0.2% of the initial population) of high dormancy seed populations were found to survive in a viable ungerminated condition. After 8 months in a similar experiment (3) with the same dormant populations 0.9% was found to survive ungerminated.

6. If either the SBBBP or indeed a wide range of populations are left on the surface of the soil during the winter so as to expose them to light, cold and moisture, these conditions will induce seed dormancy. Whether this seed

would survive ungerminated for long periods in soil if subsequently buried was not tested, but clearly to avoid this possible risk, it is not advisable to leave any *B. sterilis* population exposed on the soil surface during the winter.

SEED BEHAVIOUR IN FIELD EXPERIMENTS

1. Buried seed experiments

a) <u>The IACR Long Ashton Field Experiment</u>

<u>Methods</u>

Seed of population number 41 (the SBBBP) were either (a) sown on the soil surface, (b) buried at 5 or 25 cms immediately after shedding (8th August, 1988), or (c) buried at 25 cms after being left on the soil surface for 2 months. 16,294 viable seed (20,111 per m^2) were sown in 90 x 90 cm plots. Where seed was buried, the position of the seed in the soil was marked with plastic weldmesh placed 5 cm above and below the seed. The seed was recovered in autumn 1988, and in spring and autumn 1989 and tested for viability. The plots were protected from birds and mice. The soil type was a sandy silty clay loam.

<u>Results</u> (Table E12)

b) <u>The Boxworth Experiment</u>

<u>Methods</u>

10,000 viable seed per m^2 of two populations (the SBBBP No. 51 and the more dormant Boxworth population No. 39) were separately sown in freely draining plastic trays which were buried at various depths in the soil. The trays and seed were exhumed after 1 and 2 years and any remaining seed tested for viability using gibberellic acid in germination tests. The soil type was heavy clay.

Results (Table E13)

c) The Scottish Agricultural Colleges (SAC) Experiment

Methods

The experimental detail is the same as for the Boxworth Experiment, except that the seed was planted using the same technique as in the IACR Long Ashton Experiment, and the soil was a sandy loam open textured soil.

Results (Table E14)

No viable seed of the SBBBP (No. 41) was found at or after one years burial.

d) IACR Long Ashton Experiment to test the Boxworth burial technique versus the Long Ashton technique

The experiment was set up in a specially prepared area of land in which four large trenches (14 metres long x 1.5 metres wide and 0.60 metre deep (each one a replicate) were excavated and their bases lined with gravel. The site was slightly sloping to allow good drainage. The trenches were refilled with plots measuring 90 cms x 90 cms, either containing heavy clay soil or a sandy silty clay loam. The plots were either set up using the IACR Long Ashton Burial Technique give in a) above or the Boxworth burial technique give in b) above. Two populations of *B sterilis* seed (collected 9th - 23rd July, 1990, population nos. 41 and 39) were sown (6th - 14th September, 1990) at a rate equivalent to 15,000 viable seed per m^2, and at a depth of 20 cms. Seed was exhumed after 8 months (6th May, 1991) and the viability of the seed determined as before.

Results (Table E15)

Discussion

In experiment a) (The IACR Long Ashton Field Experiment) where the SBBBP (Pop. 41) was used, a small number of seed survived into the autumn when buried immediately after harvest, the maximum being 15 seeds out of the original 20,116 seeds per m^2. When the plots were exhumed in the following spring or autumn no viable seeds were found. Therefore provided the ground is not re-ploughed before the spring, ploughing after harvest will ensure that all the seeds either die or germinate at a depth from which they cannot emerge.

The numbers recovered by the washing technique were slightly smaller than those given by the emergence counts, but overall the numbers were very small and no significant difference was detected between the numbers given by the two techniques.

Although the percentage survival of buried seed is very low, the numbers originally shed by a *B. sterilis* population are very high (approx. 10,000 from 20 plants per m^2 in a crop of winter wheat). Therefore, even a small percentage survival can give rise to important numbers of seed remaining in the soil until the autumn. Likewise, large numbers (5 - 7% of the sown seed) of seed can survive on the surface of the soil into the autumn, and into the spring (0.3 - 0.5% of the seed sown). With this population, no seed was found on the surface the following autumn.

Where seed was left on the surface and then buried later in the autumn, this did not affect the long-term survival of the seed, for no seed was found in this treatment in the spring.

No difference could be shown statistically between survival at the 5 cms and 25 cms depth. The main advantage of the deeper burial is that seedlings cannot emerge from plough depth, and therefore no further action is needed to kill them, as would be the case if seed was shallowly buried (less than 12 cms).

In the SAC seed burial experiment, the seed was first exhumed after 1 years burial to test for any viable seed, so it is not possible to detect precisely when during the year that all the seed of population 41 had been lost. However, the result does fit in with that from the Long Ashton burial experiment, where the same population was buried, and where no viable seed was detected by the first spring after harvest. Unfortunately it is not possible to compare the survival of population 39 (the more dormant population) in the SAC and Long Ashton experiments, because population 39 was not planted at IACR Long Ashton. However, the SAC experiment verifies the findings elsewhere in this report that the more dormant populations persist for longer when buried.

The Boxworth experiment showed that seed of the SBBBP population (Pop. 41) and a more dormant population (Pop. 39) could survive for longer and in larger numbers than in the IACR Long Ashton and SAC experiments. Because of the very small numbers of seed surviving, only the first years data was subjected to a formal analysis of variance in which the data needed to be transformed using the square root transformation $\sqrt{(\text{counts} + 0.5)}$. No significant difference in the survivability of the seed of the two populations was found. However, if the maximum values for each population are considered (which for practical purposes is perhaps more relevant) then the more dormant population can be seen to be surviving in greater numbers (i.e. max survival of populations 41 and 39 after 1 year was 53 and 88 viable seeds per m^2 respectively). In the longer term there was little difference between the survivability of the two populations. After one year, the deeper buried seed survived to a significantly greater extent than the shallow seed. The reason for the difference in the results between the Long Ashton/SAC and the Boxworth Experiment is probably connected with the difference in soil type between the sites. The Long Ashton experiment was set up on light sandy clay loam, and the SAC Experiment on a sandy loam, whilst the Boxworth experiment was on a heavy clay soil. However, this result needs treating with some caution because the Boxworth experiment used a slightly different burial technique to the Long Ashton/SAC experiments.

The experiment at Long Ashton to establish whether it was the technique or soil type which was responsible for the longer term survival in the Boxworth experiment resulted in too few seeds being recovered after 8 months burial to make any definite conclusions (Table E15). It could be that soil texture, or other soil factors are playing a more important role than that of soil type. Further experimentation in this area is needed.

It can be concluded that:

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

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

3. There are certain soil types or soil 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.

4. It is essential to bury all the seed when ploughing, otherwise any seed left on 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 <u>all</u> 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.

EXPERIMENTS IN RELATION TO SET-ASIDE

Methods and results

A detailed investigation was made of when seeds on a *B. sterilis* panicle become viable. A summary of these findings is given in Fig. E5. It was found that no seeds were viable by 2 days after anthesis, but by 7 days some viable seed were present, and by 16 days all seeds in the panicle were viable. At sixteen days the seeds were found to be desiccation tolerant, although the exact time at which this occurred during the first 16 days was not determined.

Discussion

B. sterilis seeds develop viability very quickly (between 2 - 7 days) after anthesis. In set-aside situations if viable seed return is to be prevented by cutting, it is essential to cut the panicles well before the first seeds on the panicles become viable. It is suggested that the latest safe identifiable stage would be when the first panicles are just emerging from their sheaths.

AN EXPERIMENT CONCERNED WITH THE STIMULATION OF GERMINATION IN *B. STERILIS* SEED

Introduction

B. sterilis is a difficult weed to eradicate because as yet there are no reliable herbicidal or cultural control measures. This weed would seem to be an ideal candidate to be controlled by stimulating its seed to germinate and then subsequently destroying the seedlings because (i) most of the known populations shed seed which has little innate dormancy, so breaking the dormancy should not be difficult, (ii) there are no large long-term soil seed banks, (iii) it is a patchy weed, the location of the patches being known prior to harvest because of the conspicuous nature of the purple panicles.

Application of a treatment to the patches could then be made after harvest, making treatment economic, even if large area treatment was not.

Methods

Gibberellic acid (GA_3) is known to stimulate the germination of *B. sterilis* seed, including those populations readily enforced or induced into dormancy. Clearly treatment of large field areas with GA_3 would be uneconomic and so a comparable alternative 1-(3-chlorophthalimido)cyclohexanecarboxamide (AC94377) which has gibberellin-like properties was tested.

Five doses of AC94377 and one of GA_3, a water and surfactant control were separately applied to seeds in 230 mm diameter pots by three methods, (1) sprayed on to seed sown on the soil surface, (ii) sprayed on to the soil surface with seed sown 25 mm deep, (iii) sprayed on to seed sown on the soil surface and then after 24 hours the seed incorporated into the soil.

Results

A histogram of the results in given in Fig. E6. After 2 weeks, only AC94377 at the highest dose increased germination using method (i). Although increases in germination were given by both AC94377 and GA_3 using method (ii), the largest effect was observed using method (iii) in which doses between 0.5 and 2.0 kg AI/ha of AC94377 gave 91 - 92% germination, compared with 26% in the surfactant control.

Discussion

One of the difficulties of the use of germination stimulants after harvest is that it is at a time of year when moisture is very often limiting for germination. Hence even if dormancy is broken or the restriction of germination by light overcome, there may not be sufficient moisture to allow germination and therefore the destruction of the seed. However, this factor should not be a major problem provided the seed can be cultivated into the ground to a depth where there is sufficient moisture to allow germination. (It will be noted that where seed was incorporated into the soil, this gave the best germination response.)

There is no current recommendation for AC94377 to be used for the stimulation of weed seed germination. However, now that burning stubble after harvest has been banned and there may be possible restrictions in the use of some of the herbicides used to control the weed, other ways of preventing the build-up of its populations need to be found. The present research suggests that stimulated seed germination coupled with subsequent mechanical or chemical seedling destruction might provide the farmer with an alternative and efficient method of control. Further development of this effective technique is warranted.

Table E1. Germination characteristics of seed collected from 24 populations of *B. sterilis*, 1989.

Populati	Time to 50% germination weeks/days	Log (T)	Estimated max germinated u continuing co	Actual maxi of germinat 15 weeks
1	5.4	1.68	95.6	94.8
2	0.8	-0.26	86.1	85.8
4	8.0	2.08	79.8	80.1
8	7.4	2.01	48.3	49.1
9	7.4	2.00	77.8	76.9
11	15.1	2.71	88.0	87.3
14	11.1	2.40	96.3	95.8
19	1.8	0.58	99.0	99.7
26	15.3	2.73	93.8	94.0
27	2.7	0.99	99.5	99.8
28	19.8	2.99	96.3	96.3
29	2.2	0.79	88.8	88.1
31	3.7	1.30	85.4	85.9
32	3.9	1.36	86.9	86.8
33	1.8	0.57	96.0	96.0
34	11.7	2.46	24.5	25.1
35	3.0	1.09	30.8	30.9
36	14.9	2.70	86.3	86.7
38	2.6	0.95	95.1	95.0
39	21.0	3.05	68.8	69.3
40	3.2	1.17	99.8	100.0
41	14.3	2.66	74.0	74.6
42	11.3	2.43	81.5	81.7
43	31.5	3.45	80.3	80.5
LSD (P = 0.05)		0.711	4.86	

Table E2. Twenty four populations of *B. sterilis* grouped according to time to 50% germination (T_{50}) and estimated maximum germination (seeds collected in 1989 and incubated in 12 hours light/12 hours dark at 15^{0}C).

T_{50}: 2 33 19 29 38 27 35 40 31 32 1 9 8 4 14 42 34 41 36 11 26 28 39 43

Estimated max. germination: 34 35 8 39 41 9 4 43 42 31 2 36 32 11 29 26 38 1 33 28 14 19 27 40

Collections underlined were not significantly different.

Table E3. Time to 50% of the total germination (T_{50}) of the six *B. sterilis* populations in the micro-plot field experiment.

Population Number	T_{50} (days)	T_{50} (log)
34	41.5	3.600
28	7.7	2.027
40	5.0	1.430
29	4.7	1.499
39	20.2	2.945
35	14.3	2.593
LSD (P = 0.05)		0.625

35 39 34 28 40 29

Populations which are underlined are not significantly different from each other (P = 0.05).

Table E4. Total % germination of the six *B. sterilis* populations in the micro-plot field experiment.

Population Number	Total Germination (%)
34	65.3
28	91.2
40	94.9
29	96.8
39	72.2
35	60.8
LSD (P = 0.05)	12.2

29 40 28   39 34 35

Populations which are underlined are not significantly different from each other (P = 0.05).

Table E5. Number of seeds of the six different populations of *B. sterilis* remaining viable and ungerminated at the end of the field micro-plot experiment.

Population Number	Means of transformed data	Back transformed means per pot of 1,000 seed	Actual % survival of viable seed in experiment
34	11.41	129.7	18.5
28	7.27	52.4	5.4
40	5.48	29.5	3.1
29	2.88	7.8	0.9
39	14.56	211.5	21.2
35	18.80	352.9	35.8
LSD (P = 0.05)	5.127		

35 39 34 28 40 29

Populations which are underlined are not significantly different from each other (P = 0.05).

Table E6 Experiment 2, number of *B. sterilis* seeds remaining viable and ungerminated at the end of the experiment (1 year after burial).

a) Means of transformed data

Population	Surface dry	Surface wet	Overall
50	13.73	13.43	13.61
40	4.44	3.40	3.92
LSD (P = 0.05)	5.29		3.74

b) Back transformed means of the number of viable seed remaining per pot out of 1,000 seed at the end of the experiment.

Population	Surface dry	Surface wet then buried	Surface wet	Buried at start
50	189.66	0.86*	179.86	0*
40	19.21	0*	11.06	0*

* Calculated from transformed data but not included in the analysis

c) Actual percentage numbers of viable seeds remaining at the end of the experiment

Population	Surface dry	Surface wet then buried	Surface wet	Buried at start
50	19.9	0	19.0	0.2
40	2.3	0	1.4	0

Table E7. Experiment 3, percentage of seed germinating in a range of *B. sterilis* populations by 25/26 October 1990.

Population number	Surface	Buried at start	Surface then buried
27	73.0	98.0	74.3
34	17.8	96.8	16.4
35	16.3	96.8	17.1
39	44.7	96.7	46.5
40	60.8	98.3	72.7
41	79.2	97.5	77.8
LSD (P = 0.05) = 6.50			

Table E8. Number of viable ungerminated seed of a range of *B. sterilis* populations remaining in the surface sown treatment by 23 October in 1989 (Experiment 1) and 1990 (Experiment 3).

	Population number					
	29	40	28	34	39	35
Experiment 1	3.9	6.5	10.0	54.4	28.4	43.6
Experiment 3	-	39.2	-	82.2	55.3	83.6

Table E9. Experiment 3, total percentage germination/emergence of each population of *B. sterilis* in each treatment by the time of exhumation (4 April 1990).

Population number	Treatment		
	Surface	Buried	Surface then buried
27	77.8	98.0	95.6
34	22.6	97.0	98.2
35	17.4	96.8	94.0
39	48.3	96.7	95.4
40	63.2	98.3	97.1
41	82.8	97.3	94.0
LSD (P = 0.05) = 5.99			

Table E10. Experiment 3, number of seed of *B. sterilis,* population numbers 34 & 35, remaining viable and ungerminated in the buried and surface then buried treatments at the time of exhumation (4 April 1990).

Population number	Numbers of seed remaining out of 500 viable seed originally planted	
	Buried	Surface then buried
34	1.5 (0.3%)	0.25 (0.05%)
35	0.5 (0.1%)	4.25 (0.9%)

Table E11. Experiment 3, percentage total germination in the surface sown treatment of each population of *B. sterilis*.

	Population number					
	27	34	35	39	40	41
% Mean total germination	96.9	78.2	90.9	91.5	96.8	94.0
LSD (P = 0.05) = 9.97						

Table E12. Survival of viable ungerminated *B. sterilis* seed in IACR Long Ashton field experiment.

a) Percentage survival of viable seed

	Date of Recovery		
Burial depth	Autumn 1988	Spring 1989	Autumn 1989
Surface	4.83 - 7.37*	0.50 - 0.34*	0
5 cms		0	0
25 cms	0.008 - 0.075*	0	0
Surface for 2 mths. then buried at 25 cms	-	0	0

a) Numbers of seeds surviving per m^2

Burial depth	Autumn 1988	Spring 1989	Autumn 1990
Surface	972.2 - 1482.4*	101.2 - 68.5*	0
5 cms	1.5 - 15.1*	0	0
25 cms	2.5	0	0
Surface for 2 mths. then buried at 25 cms	-	0	0

* Figures obtained from emergence counts which in most cases gave slightly higher values in contrast to the other figures which were obtained by exhumation and laboratory germination tests. No assessment of emergence from the 25 cm depth was possible because seedlings cannot emerge from this depth.

Table E13. Survival of viable ungerminated *B. sterilis* seed in the Boxworth field experiment.

Population No.	Depth of burial	Year 1 (1989)		Year 2 (1990)	
	(cms)	%	per m^2	%	per m^2
39	5	0.13	13.2	0.06	6.6
	10	0.06	6.6	0.02	1.7
	15	0.88	87.6	0	0
	20	0.45	44.6	0.03	3.3
41	5	0.10	9.9	0.02	1.7
	10	0.17	16.5	0.02	1.7
	15	0.35	34.7	0	0
	20	0.53	52.9	0.06	6.6

Table E14. Survival of viable ungerminated *B. sterilis* seed in the SAC field experiment.

Population No.	Depth of burial	Year 1 (1989)		Year 2 (1990)	
	(cms)	%	per m^2	%	per m^2
39	5	0.03	3.17	0	0
	10	0.06	6.35	0	0
	15	0	0	0	0
	20	0.06	6.35	0	0

Table E15. IACR Long Ashton soil/technique experiment, number of *B. sterilis* seed remaining viable and ungerminated after 8 months burial in two soil types using two burial techniques.

Population	Soil Type	Technique	Ungerminated viable seed	
			%	m^2
41	Clay	Box	.017	2.5
	Clay	L. Ashton	.004	0.6
	Sand	Box	0	0
	Sand	L. Ashton	.002	0.3
39	Clay	Box	0	0
	Clay	L. Ashton	0	0
	Sand	Box	0	0
	Sand	L. Ashton	0	0

FIG. 1 % GERMINATION OF VIABLE SEEDS OF BROMUS STERILIS POPULATIONS AFTER 28 DAYS AT 15°C IN 1) 12 HOURS LIGHT / 12 HOURS DARK AND 2) + CONTINUOUS DARK

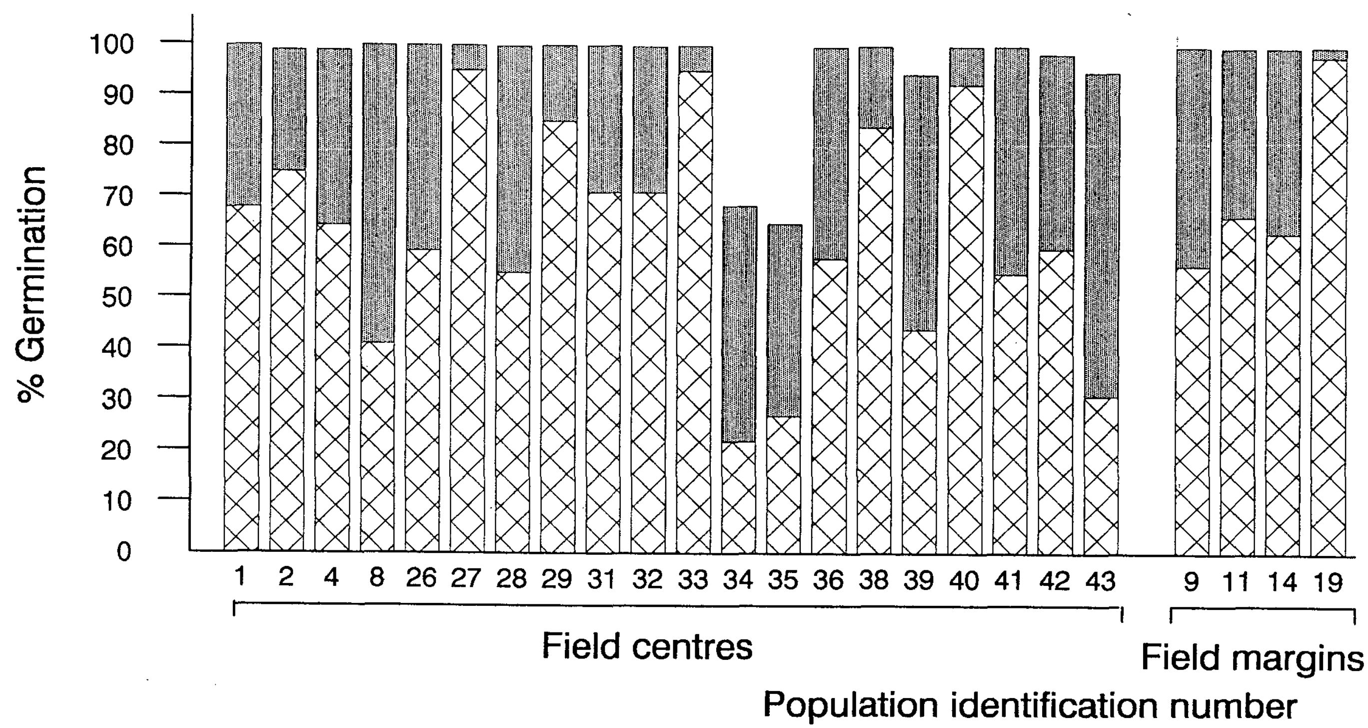


FIG. 2 GERMINATION OF DIFFERENT POPULATIONS OF B. STERILIS ON THE SOIL SURFACE

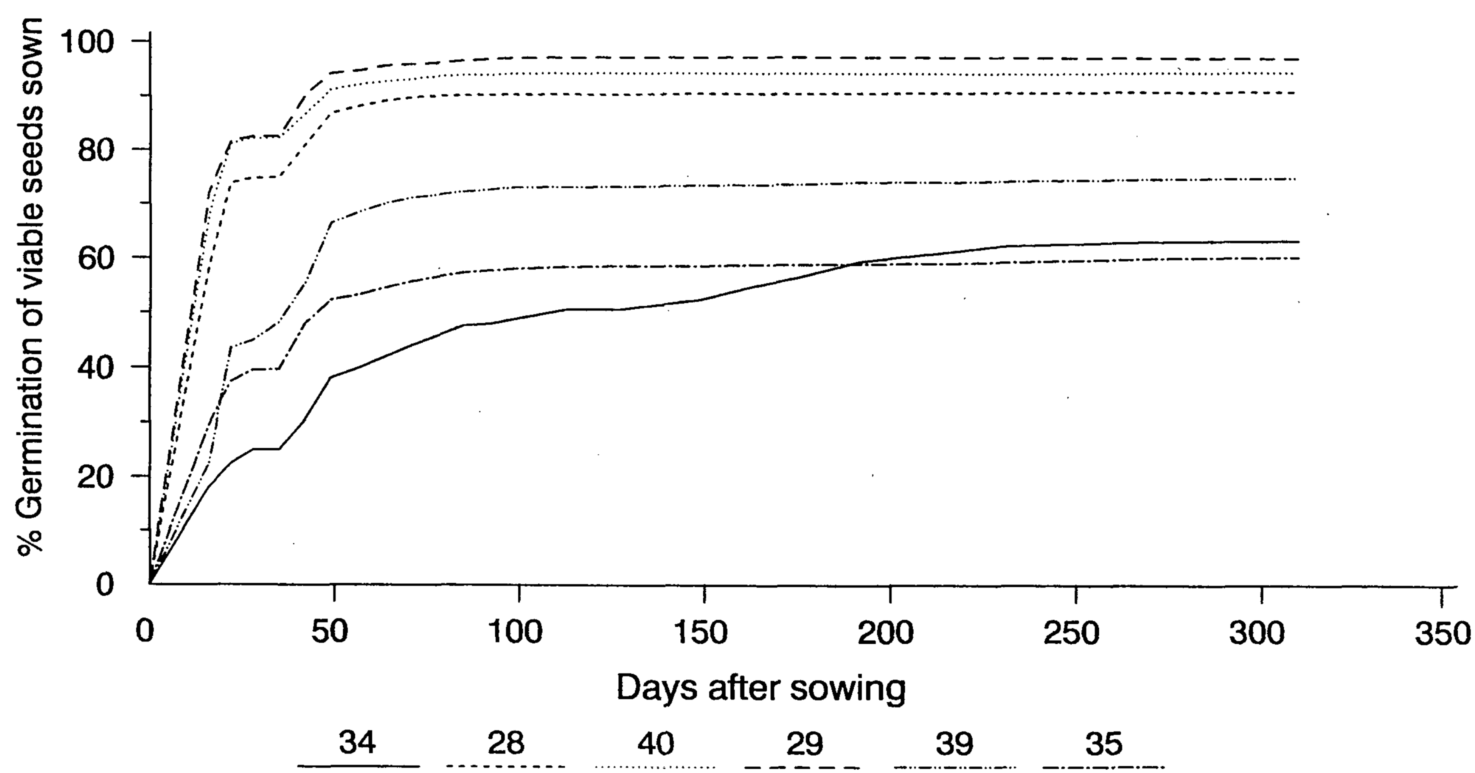


FIG. 3. GERMINATION OF B. STERILIS SEEDS AFTER VARIOUS BURIAL AND SOIL SURFACE TREATMENTS

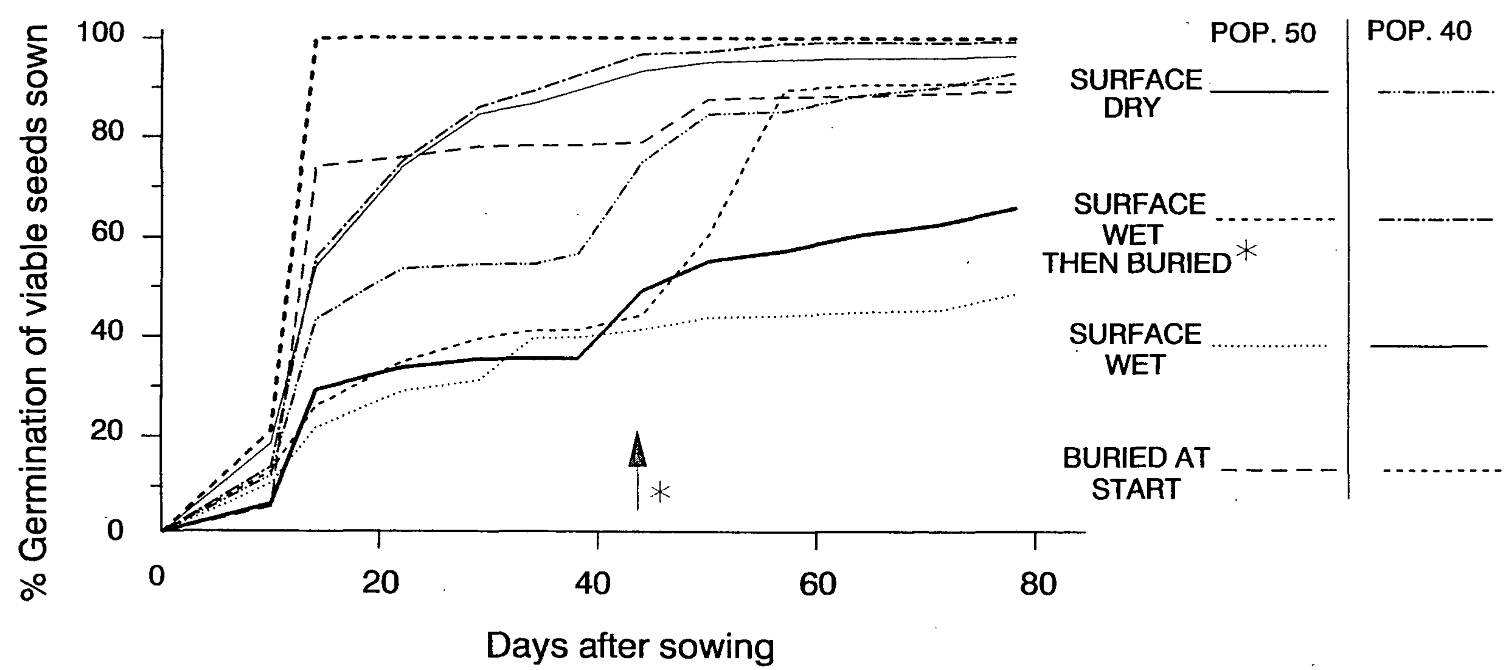


FIG. 4. INDUCTION OF DORMANCY IN BROMUS STERILIS
[Seed exposed on soil surface Aug 10/90 - April 4/91]

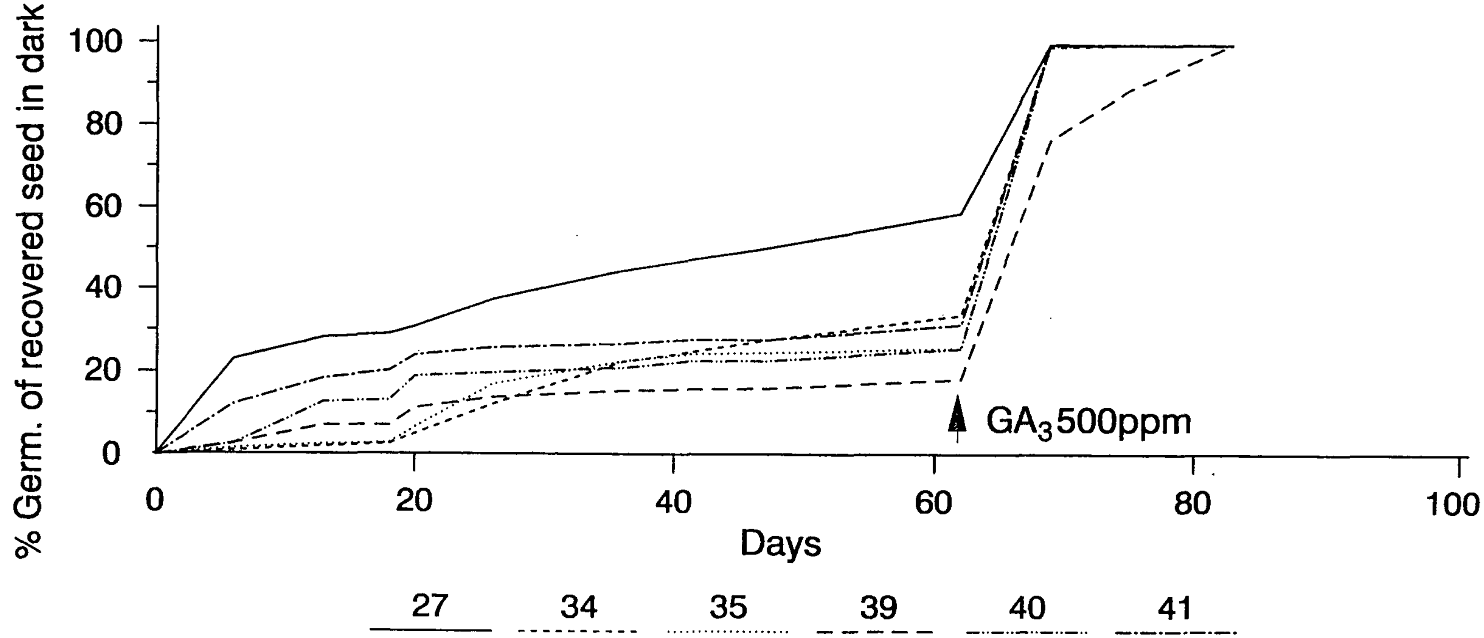


FIG. 5. TIMING AND SEED DEVELOPMENT IN BROMUS STERILIS

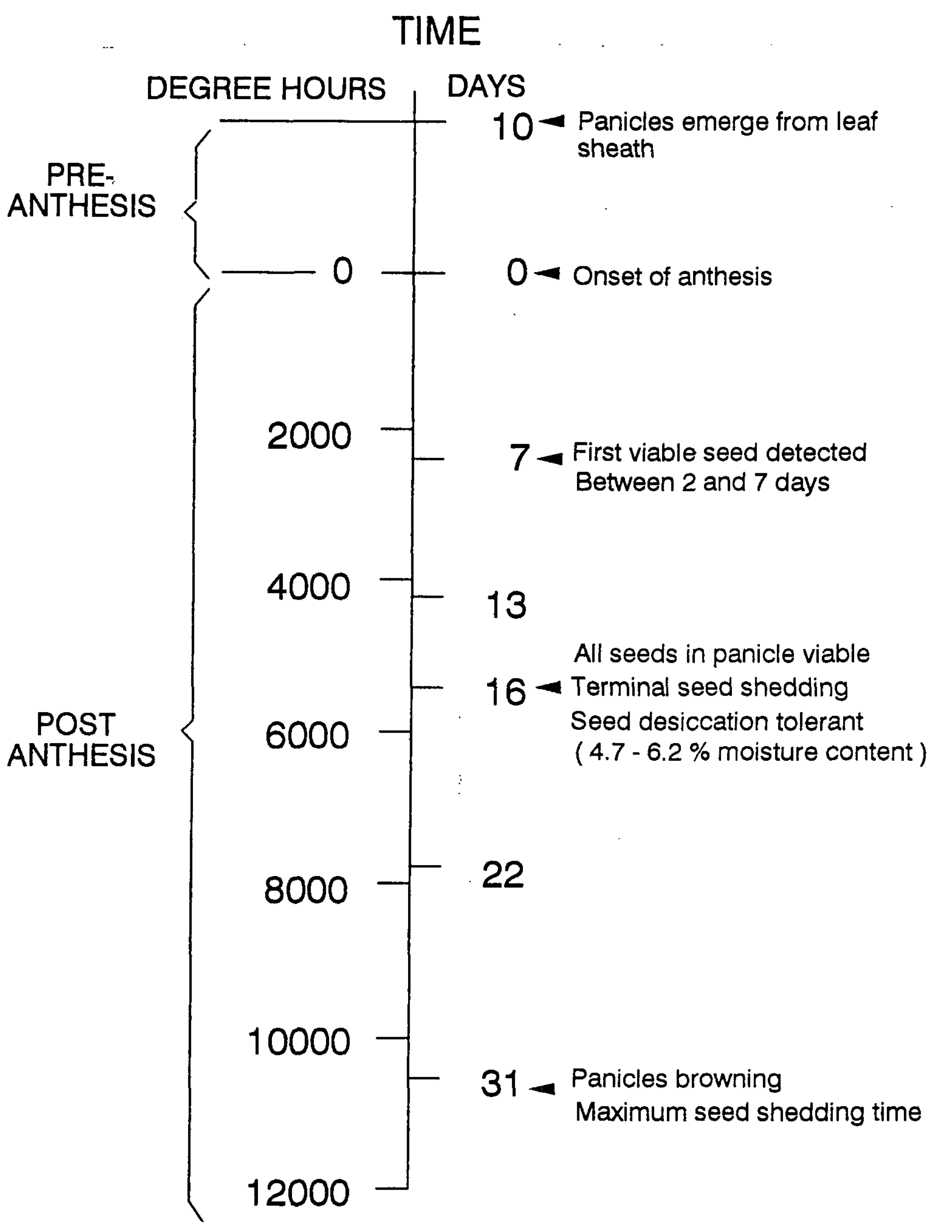
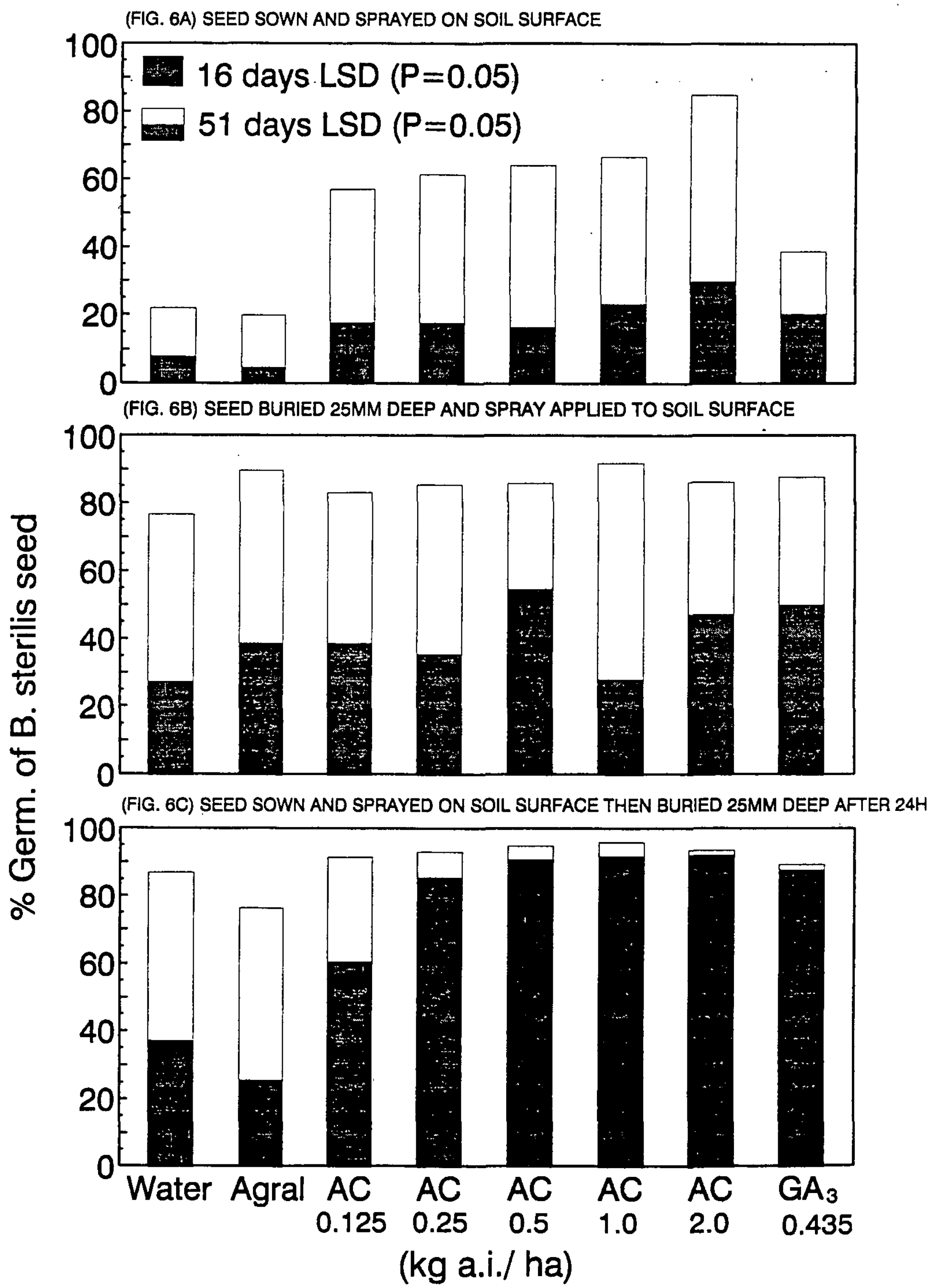


FIG. 6. EFFECT OF AC94377 (AC) AND GIBBERELLIC ACID (GA_3) ON THE GERMINATION OF <u>B. STERILIS</u> SEED ASSESSED 16 & 51 DAYS AFTER SPRAYING



INTRODUCTION

With the continuing swing to winter cropping in recent years and the gradual disappearance of freely-germinating cultivars such as Golden Promise from the spring-sown acreage, there is concern that volunteer barley problems could be on the increase. In many cereal-based rotations the interval available between harvest and sowing of the next crop for the emergence and control of volunteer seedlings is much shorter than in previous years. All barley cultivars exhibit a degree of dormancy immediately after harvest, which can cause problems for maltsters and is particularly important in spring cultivars harvested late under adverse conditions and in winter cultivars generally. If post-harvest dormancy were more prevalent in modern cultivars and if this in turn led to delays in the germination of grain shed at harvest, it could reduce the usefulness of control strategies based on encouraging maximum germination of shed grain in the stubble.

Burial of shed seed to a depth from which seedlings are unable to emerge is another control strategy which could be affected by differences in post-harvest dormancy between cultivars. Prolonged dormancy could assist control in the short term, by discouraging emergence in an autumn crop from seeds inadequately buried, but it might lead to volunteer seedlings from these seeds appearing in crops later in the rotation. This project examined the behaviour of freshly harvested seeds of a range of barley cultivars buried at different depths in soil and investigated the relationship with laboratory tests on post-harvest dormancy.

OBJECTIVES

To investigate germination and survival in the soil by freshly-harvested barley seeds of different cultivars and to study the relationship between field behaviour and laboratory dormancy tests.

METHODS

Grain samples were harvested from a total of nine autumn and spring-sown barley experiments spread over a four year period. The field experiments formed part of the SCRI cereal genetics research programme, funded by SOAFD. In 1988 and 1989 each field experiment contained a range of genotypes and two levels of an agronomic factor. In 1990 and 1991 the experiments concentrated solely on genotype comparisons. All field experiments were laid out as replicated randomised blocks. Harvesting took place when the grain on all the relevant plots was combine-ready (ca. 20% moisture content). Enough ears were hand-harvested to provide approximately 2 kg of grain after hand-threshing and a random selection of 100 seed-lots was chosen for pot trials and laboratory tests. These were carried out using the same randomised layout as in the original field experiment, usually with three replicates of each treatment.

Seeds were sown, within 24 hours of hand-threshing, in steam-sterilised loam soil in 30 cm diameter pots which were then sunk to the rim in a permanent standing area adjacent to the SCRI agro-meteorological site. Each pot contained 100 seeds sown on top of a plastic mesh sited precisely at a depth of 3, 11.5 or 20 cm below the final soil surface. Emergence of seedlings was recorded at regular intervals until late autumn. In March of 1989, 1990 and 1991 the pots were lifted, overwintered seedlings removed and the soil sieved to recover any remaining seeds. Dead or already germinated seeds were discarded, but potentially viable seeds were replanted at 3 cm depth in their pots, which were returned to the standing area. Seedling emergence was recorded until late June. In the final year seeds were excavated in January and their viability assessed in the laboratory.

Other seed-lots were subjected to periodic laboratory germination tests until it was apparent that post-harvest dormancy had largely disappeared. These tests involved various factorial combinations of temperature (18-20 or 10°C), illumination (light or dark) and water supply (4 ml or 8 ml per Petri dish). They included three standard tests for dormancy:

Germinative Energy (GE) - 100 grains germinated in daylight at 18-20°C in a 9 cm Petri dish on two Whatman No. 3 filter papers, with 4 ml of distilled water added. Germinated grains counted after 3 days.

Germinative Capacity (GC) - as GE, but counted after 5 days.

Water Sensitivity (WS) - as GE, but with 8 ml water.

The final year viability assessment commenced with the GC test; further 4 ml quantities of water were added at intervals as required until it was clear that no further germination would take place under those conditions. Remaining seeds were then treated with a 200 ppm concentration of gibberellic acid in 4 ml water to overcome any residual dormancy.

RESULTS

The agronomic treatments imposed on the field experiments harvested in 1988 and 1989, including staggered sowing dates, different seed rates and two levels of nitrogen applied to the seedbed, had no effect on the performance of harvested seeds in any pot trial or laboratory test. The two factors which did affect seed performance were year of growing and cultivar and this report concentrates on these aspects of the nine experiments, with results pooled, where appropriate, across agronomic treatments.

In 1988 weather conditions in the period leading up to harvest were unusually wet and windy and both autumn-sown crops became badly lodged; some 50 mm of rain fell over the two weeks prior to the two harvest dates, with rainfall recorded on at least 11 of the 14 days. The appearance of the harvested grain was poor. In the other three years, rainfall during the fortnight before harvest averaged 19, 8 and 13 mm respectively; there was no lodging and grain was harvested in excellent conditions.

Pot experiments

Overall seedling emergence from 3 cm depth in autumn 1988 was very much poorer than that achieved in later years (Table F1), which fluctuated between 65 and 93%. Emergence from 11.5 cm in 1990 and 1991 ranged between 7 and 30%. No seedlings emerged from 20 cm in three of the experiments and the highest number recorded was an average of 0.4 seeds per 100 sown in a 1990 trial. Seedlings first appeared from 3 cm depth 1-2 weeks after sowing (Table F2). The soil used for the pots was relatively dry when the seeds were sown and the pots were not watered before or after setting out. Adequate natural rainfall was therefore required to encourage seed germination. First emergence occurred earliest in trials where a wetting rain fell within a few days of sowing. Peak emergence from 3 cm (defined as the day by which 90% of those seeds which eventually produced seedlings had done so) was also linked to rainfall, particularly in the three trials where no substantial rain fell for several weeks after sowing (Table F2). In two experiments where the soil surface had remained dry for several weeks after sowing, the first seedlings emerged earlier from 11.5 cm than from 3 cm depth, although final numbers were much greater from the shallower depth.

Cultivars varied considerably in speed and total percentage emergence from 3 cm depth in autumn. In both autumn-sown trials in 1988 Igri seedlings appeared earliest and reached a final total of 38% emergence. This compared with averages achieved by Halcyon and Golden Promise of 18% and 9% respectively. In a similar trial in 1989 Halcyon and Igri reached 83% final emergence, compared with 63% for Golden Promise, although speed of emergence was similar for all three cultivars. An adjacent trial showed no differences in either respect amongst Igri, Halcyon and Magie, the final numbers averaging 93% of the sown population. In a spring-sown trial in 1989 Klaxon and Doublet emerged more quickly than Natasha and particularly Digger. However, final totals averaged 78% with little difference between cultivars.

Tables F3 and F4 summarise the response of winter and spring cultivars to burial at 3 and 11.5 cm depths in 1990 and 1991. In both years Marinka seedlings emerged earliest in autumn from both depths and achieved the highest final populations amongst the winter cultivars. Gaulois, Halcyon and Pipkin seedlings behaved similarly from 3 cm in 1990, but Gaulois was slightly superior from 11.5 cm. Pastoral and especially Magie seedlings were slow to emerge from 3 cm, but caught up later. Magie performed much better than Gaulois from 3 cm depth in 1991, but the opposite applied from 11.5 cm. Halcyon showed the poorest final emergence from 3 cm, while Pastoral produced hardly any seedlings from 11.5 cm. Overall emergence of cultivars from 11.5 cm was similar in both years, but results were poorer from 3 cm in 1991 than in 1990. Too few seedlings emerged from 20 cm for inclusion in the analysis.

Golden Promise, Doublet and Triumph behaved very similarly to one another in seedling emergence from 3 cm depth in both years, reaching high final counts. Doublet was the best and Golden Promise the poorest of the three from 11.5 cm depth. Klaxon and Natasha showed poorer final seedling emergence from 3 cm than the above cultivars in 1990, but not in 1991, although Klaxon seedlings emerged later and Natasha seedlings earlier than the rest in the second year. Digger gave by far the poorest performance at this depth in both years. From 11.5 cm Klaxon ranked higher than Natasha and Digger in both years. Overall seedling emergence from 11.5 cm depth was considerably better in 1990 than in 1991. Other than with Digger, there was relatively little variation between the two years in emergence from 3 cm. No relationship was detected between seed size of winter and spring barley cultivars and their ability to emerge from 11.5 cm.

Table F5 summarises the percentage of each seedbank which had not produced seedlings in autumn and the percentage which was recovered live and ungerminated when excavated. A small proportion was always unaccounted for in all pots; these latter seeds had presumably rotted. Seeds which had germinated at 11.5 or 20 cm, but died before producing shoots above the soil surface accounted for a high percentage of the dead seeds recovered from these pots. The numbers of seeds recorded as live and ungerminated varied considerably with depth and between years. Approximately one-half and one-third of the seeds which did not produce seedlings from 3 or 20 cm depths respectively in autumn 1988 were found to be viable in spring 1989, whereas very few live seeds were found at either depth in spring 1990. A lower proportion was recovered following burial in 1991 than in 1990. Overall, there was considerable mortality over winter at all three depths of seeds which had failed to produce seedlings in the previous autumn. Nevertheless, appreciable numbers of seeds did survive in most years. Although in all but the final series of trials every potentially viable seed was replanted at 3 cm depth and the pots were returned to the outdoor site, to simulate the effect of bringing seeds near to the soil surface during seedbed preparation in spring, very few produced seedlings. Seeds sown in autumn 1991 were excavated in January and surviving live seeds had their viability assessed in the laboratory, with the aid of gibberellic acid (GA). While few were able to germinate in water, almost all responded to the application of GA.

Laboratory tests

Differing degrees of dormancy were evident in grain samples examined using the GE test shortly after harvest and their persistence varied considerably between years and between winter and spring crops (Table F6). In the 1988 tests overall figures mask the fact that Igri seeds showed only 55-60% germination in early November, but that this had risen to 90% by the end of that month. Halcyon and Golden Promise had already lost post-harvest dormancy by early November. In 1989 immediate post-harvest tests on one autumn-sown crop showed relatively little dormancy with Golden Promise, but only 75% of Halcyon and 49% of Igri seeds germinated at that time. In the second autumn-sown crop Halcyon and Magie showed little dormancy, but only 32% of Igri seeds germinated. A few weeks later dormancy had disappeared from all cultivars except Igri in Experiment IV. With the spring-sown crop, Doublet at 62% produced double the germination shortly after harvest of that achieved by Digger, Klaxon and Natasha, but dormancy had gone from seeds of all four cultivars one month later.

In 1990 all cultivars demonstrated very severe post-harvest dormancy, which not fully overcome until October or November (Table F6). Pipkin and Marinka were the least and Gaulois the most affected of the winter cultivars (see also Table F7), while Golden Promise was the least and Triumph and Digger the most affected of the spring cultivars (see also Table F8). In 1991, using all the same cultivars except Pipkin, post-harvest dormancy of winter barley was as severe as but even more prolonged than in the previous year (Table F6). Marinka showed least dormancy, while Pastoral and

Halcyon were by far the most affected initially and still showed the lowest germination in November tests. Of the spring-sown cultivars Golden Promise and Doublet were least affected by post-harvest dormancy in 1991. Natasha, Triumph and Digger were much more dormant initially, but germination counts eventually caught up with those of the other cultivars in successive tests.

Keeping samples for a further two days (the GC test) increased the total number of seeds germinated, slightly in some trials and quite considerably in others, but did not affect the relative performances of the different cultivars. Adding extra water (the WS test) consistently reduced germination, sometimes very severely. Apart from the standard dormancy tests, various combinations of temperature, illumination and water supply were examined to establish which factors stimulated or inhibited germination and how these affected the relationship between cultivars. There is not room to present data for all tests at all dates in all trials, but Tables F7 and F8 illustrate the effects using 1990 data from 3-day tests. Reducing the temperature to 10°C and conducting the tests in the dark increased overall germination without influencing the relative performance of cultivars. Increasing the water supply to the seeds had a major deleterious effect on germination and altered the ranking order of both spring and autumn cultivars. In both trials there was also a significant interaction between illumination and water supply; better germination in the dark than in the light was less marked if excess water was present. Greatest differences between cultivars were evident immediately after harvest and diminished progressively with successive tests.

Relationships between pot experiments and laboratory tests

No consistent relationship was detected between the degree of immediate post-harvest dormancy and the speed or completeness of seedling emergence from 3 cm depth in autumn (Table F9). The relatively high overall levels of dormancy detected by the GC tests in freshly-harvested grain in the 1990 and 1991 experiments were not reflected in poor emergence records in the pots. In 1989, when immediate post-harvest dormancy was less severe, seedling emergence corresponded fairly closely with laboratory germination using the GC test. In all but one of these experiments GE tests on freshly-harvested grain greatly underestimated seedling emergence from seeds sown at 3 cm depth at that time. Both tests carried out on stored grain four or more weeks after harvest gave a much better approximation to pot results, but by this time seedling emergence had already finished, unless dry soil conditions had caused a delay. The WS test showed little or no relevance to these trials, but related reasonably well to the poor levels of pot emergence in the 1988 experiments. Of the various modifications to the tests evaluated, best results in comparison with overall seedling emergence records in individual experiments were obtained by placing seeds in the dark at 10°C with 4 ml of water and counting those which had germinated after 5 days (Expts VII-IX in Table F9).

On an individual cultivar basis, Igri seedlings emerged from 3 cm depth more quickly and in greater numbers than those of other cultivars in 1988 and 1989, despite showing the highest level of post-harvest dormancy in all four trials. In contrast, Golden Promise was much less affected by post-harvest dormancy than most other cultivars in the six experiments in which it was included, but performed no better than several other cultivars, including Triumph, in the pot trials. Marinka scored highly in both pot and immediate post-harvest dormancy tests on winter cultivars in 1990 and 1991, whereas Pastoral gave one of the poorest performances in laboratory tests and was slow to emerge in pot trials. Digger was one of the lowest ranking of the spring cultivars in early laboratory tests in both years and was also by far the poorest in terms of seedling emergence in both 1990 and 1991. Other cultivars showed no particular agreement or disagreement between the two types of assessment.

DISCUSSION

In the pot experiments, burial of volunteer barley seeds to 20 cm depth shortly after harvest prevented between 99.6 and 100% of these seeds from producing seedlings that autumn. These results applied to nine experiments over four years, encompassing a wide range of winter and spring cultivars. Field experiments by collaborating workers at Rothamsted, Boxworth, Bridgets and Bush have also shown little emergence from that depth. Our figures were generally lower, due probably to more accurate depth placement in pots than is possible by ploughing. In theory it would not require burial of seeds to much greater depth than 20 cm to ensure nil emergence. In practice efficient burial of seeds to a uniform depth on a field scale is very difficult to attain. Nevertheless, this must be the most effective way of avoiding problems in a subsequent winter crop. The efficiency of the technique will be improved if steps are taken to minimise grain losses during harvest by appropriate combine harvester settings, to plough as deeply as possible with good furrow inversion and to avoid bringing seeds back up to shallower depths during seedbed preparation.

Emergence in autumn from 20 cm depth was so sparse in the pot trials that no comparisons between cultivars or seasonal conditions could be made. These were possible with seedlings emerging from 11.5 cm, where final counts averaged under 10% in three trials, but 30% in a fourth trial. Of the winter cultivars, Marinka and Gaulois produced most seedlings from this depth in both 1990 and 1991, while Doublet and Klaxon were the most productive of the spring cultivars in both years. There was little to choose between the other cultivars examined. These results suggest that the penalties for inefficient burial of shed barley seeds may be consistently greater with some cultivars than others and in some seasons than others. This should be taken into account when the efficacy and economics of different burial strategies, such as the comparisons between tine cultivation and ploughing to different depths at Rothamsted and ADAS Research Centres, are being considered.

Reasons for the better emergence of seedlings of spring barley cultivars from 11.5 cm in 1990 as compared with the performance of the same cultivars in 1991 or that of winter cultivars in 1990 or 1991 are not clear. It was not matched by better emergence from 3 cm in the same experiment and there were no obvious differences between pre- or post-harvest conditions affecting this and the other three trials. The ability of a cultivar to produce seedlings from 3 cm and from 11.5 cm depths was not necessarily related. However, Marinka was the quickest of the winter cultivars to emerge from both depths in 1990 and 1991 and gave the best final seedling counts from 11.5 cm, while Digger was the slowest spring cultivar to emerge from 3 cm and gave the poorest seedling counts from 11.5 cm in both years. This suggests a link between these factors which merits further investigation. The behaviour of other cultivars was not as clear-cut and there were significant cultivar:depth interactions in all four experiments. Seedling emergence records did not reflect differences in seed size at harvest. Depth of burial of seeds therefore imposes differences between cultivars in seedling emergence over and above those which may relate to pre-harvest conditions. However, the deeper the burial the less such differences will matter.

While burial to 11.5 cm prevented up to 90% of seeds from producing seedlings that autumn in three experiments, this level of control is unlikely to be adequate in many field situations, where even 1% of shed grain producing seedlings can lead to very large volunteer populations per unit area. As with burial at 20 cm, our results at 11.5 cm were better than those from similar depths in associated field experiments at other centres, again probably due to more precise placement of seeds. Further research is needed to examine the reasons why some seeds in a seed lot of a cultivar can produce seedlings from 11.5 cm depth while the majority cannot. This would require the use of much larger quantities of seed than could have been accommodated in the current project. Information from a wider range of depths would permit modelling of the response of seeds to depth of burial.

Seeds were sown at 3 cm depth in the pot experiments to simulate very shallow incorporation without imposing depth restrictions on emergence. The objective was to study seedling production in autumn in the absence of interference by depth and by factors such as predation, the presence of straw, or a compacted soil surface. The effects of these latter factors have been examined in field experiments by other colleagues involved in the overall project.

Total seedling emergence by individual cultivars from 3 cm depth in autumn ranged between 7% and 97% of the seeds sown over the nine experiments and four years. Emergence was particularly poor in 1988. This was probably linked to the prolonged period of wet weather during ripening and the severe lodging of the crops before harvest (Pickett, 1988). However, even following the much more favourable ripening and harvest conditions of the next three years, 21% of pots recorded less than 66% emergence and only 26% of pots showed over 90% emergence. The latter records were due entirely to two winter barley experiments (in different years) in which virtually all cultivars reached this level of emergence. No time limit was placed on seedling emergence in pot trials, so the results represent the full potential of the seeds to produce seedlings over the whole autumn period. The range and variability of the emergence rates obtained suggest that attempts to eliminate the potential volunteer barley seedbank by encouraging germination of seeds at or near the soil surface in cereal stubbles are unlikely to be successful, no matter how long an interval is available between crops.

In practice, there are limits on the time available for emergence in most autumns and an examination of the results in relation to timing of emergence in the various trials highlights a number of points. Over the nine experiments, the first seedlings always appeared 1-2 weeks after sowing at 3 cm depth. Peak emergence occurred anywhere from 3-28 days thereafter, but normally within 3 weeks of sowing. The exceptions were the three experiments in which dry soil conditions delayed peak emergence substantially (Table F2). In general, therefore, given adequate soil moisture virtually all the seedlings likely to emerge in autumn from 3 cm depth had done so within 3 weeks regardless of pre-harvest conditions or of whether the final percentage emergence achieved was high or low. It appears that a 3 week interval between seed incorporation and seedling control operations in the stubble would be sufficient in most situations to ensure maximum emergence of those seedlings capable of doing so from 3 cm depth. This could be a slight overestimate, since seeds in the pots relied for moisture on rainfall after sowing, whereas under field conditions adequate soil moisture might already be present at the time of seed incorporation. In very dry conditions, on the other hand, it might be necessary to wait until up to 3 weeks after a wetting rain has fallen. Thus, although the encouragement of germination by shallow cultivation of stubble may not prevent substantial numbers of dormant seeds from entering the seedbank and posing a potential problem later in the rotation in subsequent years, it should provide the opportunity to deal with the majority of seeds **capable** of producing seedlings after harvest. This must reduce the risk of barley volunteers appearing in a crop drilled a few weeks later, unless the cultivations associated with the drilling operation trigger germination by shallowly-placed seeds which did not respond to the first cultivation treatment, a point which needs to be investigated further. Results from field experiments at Rothamsted have shown that the use of a non-selective herbicide was more effective than soil cultivation in controlling volunteer seedlings in stubble prior to seedbed preparation.

In general, there were much greater differences between experiments than between cultivars in seedling emergence from 3 cm depth. The higher the overall level of emergence in an experiment, the smaller were the differences amongst the cultivars. This suggests that if conditions are favourable all cultivars can show high levels of seedling emergence in autumn, which seems only logical in a cultivated crop, but that some cultivars may be better able to cope than others under less favourable conditions. Examples of the latter include the much better performances of Igri than Halcyon or Golden Promise in the 1988 trials, of Marinka than Halcyon, Gaulois and Pastoral in 1991, and of all other cultivars than Digger in both 1990 and 1991. As with performance from 11.5 cm depth, speed of emergence may be an important factor in establishing differences between cultivars in emergence from 3 cm under difficult conditions.

When seeds were excavated from the pots in spring (or in January in 1992), a high proportion of those found dead at a depth of 20 cm had in fact germinated and then died. More germinated seeds were also found at 11.5 cm than could be accounted for by seedling counts. However, it was not possible during excavation to avoid separating seeds from their seedlings at 3 and 11.5 cm depth, so that germinated seeds which had produced seedlings above ground could not be distinguished from those which had failed to do so from those depths. Nevertheless, it was clear that many buried seeds did germinate at below depths from which they were capable of producing emerged seedlings. These, plus seeds found dead but ungerminated and those which had rotted over winter contributed to a very substantial depletion of the buried seedbank in all experiments. This was particularly the case with seeds from 1989 harvested experiments, regardless of sowing depth or cultivar.

When replanted at 3 cm depth few of the viable seeds produced seedlings during spring and early summer, regardless of initial depth of burial. Numbers were too low to permit comparison of burial strategies or of cultivar response. Superficially, if 4% or less of the grain shed in a stubble produces seedlings in a crop sown the following spring, a very high degree of control has been obtained. In practice this can still result in large numbers of volunteer seedlings appearing in that crop. As with autumn-sown crops, the most effective strategy for avoidance would be burial of the seeds after harvest to at least 20 cm depth and the use of shallow seedbed cultivations which do not bring overwintered seeds back up to a depth from which they could produce seedlings.

There were three possible explanations of why the remainder of the seeds re-sown in the pots in spring had not produced seedlings. Either they had been incorrectly recorded as viable, or they had died after sowing, or they had remained dormant. It was not practicable to excavate the pots again to seek survivors, but some indication of the potential of overwintered seeds to persist beyond a spring crop situation was required. Hence laboratory tests were carried out on the viable seeds recovered from the 1991 experiments instead of re-sowing. These tests suggested that failure of viable seeds to produce seedlings when replanted in spring in the earlier experiments may have been due to continuing dormancy. Although the great majority of seeds recovered from all three depths in winter 1991-92 and classed as viable did not germinate in GC tests, they did do so in response to the application of gibberellic acid to overcome dormancy. This confirmed the accuracy of the assessment of viability of overwintered seeds in these trials and suggested that seedbed preparation in spring may not necessarily trigger germination by overwintered barley seeds. This aspect of dormancy requires further investigation, since it may yield vital information as to why volunteer plants have been appearing in crops several years after the original grain was shed. Again, it would need the use of much larger quantities of seed than were possible in these experiments.

One of the aims of the project was to find laboratory tests capable of assessing the state of dormancy of seeds at the time of shedding. The three Institute of Brewing tests used in these experiments were all capable of achieving this objective and had the additional benefit of allowing direct comparison with the results of large numbers of routine samples carried out every year to assess dormancy characteristics in breeding programmes and in malting tests. Results from the individual experiments agreed well with those from tests carried out each year on seeds from other trials in the SCRI cereal genetics programme (R.P. Ellis, personal communication). These confirmed the tendency for cultivars like Igri and Triumph to show more, and of cultivars such as Golden Promise and Doublet to show less, post-harvest dormancy than many other cultivars and selections. The tests were cheap and easy to carry out and periodic repeats permitted assessment of the persistence of dormancy as the autumn progressed. The tests also gave comparable results to those from sand-culture tests carried out in related experiments at Rothamsted.

Unfortunately, these tests when carried out immediately post-harvest in 1989, 1990 and 1991 did not consistently forecast seedling production by seeds sown at 3 cm depth that time and tended to underestimate seedling emergence in seasons where post-harvest dormancy was of importance. In the latter cases, successive tests gave higher germination counts as post-harvest dormancy diminished in the stored grain samples, but the most favourable of the laboratory tests was not showing results comparable with seedling counts recorded in the pots until well after the great majority of seedling emergence had already taken place. Also, the modifications to the tests which improved seed germination in the laboratory were really only overcoming the effects of post-harvest dormancy as determined by the standard tests. This suggests that conditions in the soil in early autumn can overrule some of all of the effects of post-harvest dormancy as measured by the GE and GC tests. The potential problem with this type of dormancy in relation to seedling emergence in autumn may not therefore be as great as was originally feared.

Other forms of dormancy, such as those enforced by wet, cool conditions during grain development (as in 1988), or by dry or very wet soil conditions after shedding, may well be more important, but may not be identified by laboratory tests on stored grain. It is not possible to comment in this report on whether or not these laboratory tests would more closely match seedling production in autumn by seeds left on the soil surface.

Modifying the laboratory test parameters by reducing the temperature and carrying out the tests in the dark improved the relationship with overall seedling emergence in the pots and may reflect some of the factors which influence germination under soil conditions in autumn. However, these modifications did not change the ranking order of cultivars in early laboratory tests, which frequently bore little relationship to that in the pots. The factor which had the most drastic adverse effect on laboratory germination and to which cultivars reacted differently was excess water supply. This may be a useful pointer to problems which might be encountered by seeds in a wet autumn and to how different cultivars might react in waterlogged soil. Such conditions were not encountered post-harvest in the four years of these experiments, but pre-harvest conditions in 1988 were wet and cool and the WS test conducted in November of that year gave a better overall correlation with pot seedling counts than either of the two other tests. Unfortunately, it also ranked Igri as still showing greater dormancy than other cultivars, although it had produced the largest numbers of seedlings in the pot trials.

Overall, while the laboratory tests clearly identified those years and those cultivars in which post-harvest dormancy was a potential problem, this appeared to have relatively little to do with seedling production by seeds shallowly incorporated into soil immediately post-harvest. Although reasonable correlations could be obtained between seedling production and standard laboratory tests carried out once post-harvest dormancy had diminished considerably in the stored grain, this served no useful purpose from the point of view of forecasting. If post-harvest dormancy of the type identified by the laboratory tests is of little relevance to seedling production by buried seeds in autumn, a method of identifying and forecasting the effects of other more important dormancy factors is still needed. This may require experimentation in a controlled environment, since the likelihood of the necessary range of environmental conditions occurring in field experiments over a short span of years is unpredictable.

Dormancy is a natural mechanism which causes germination to be delayed until conditions are suitable for plant growth. This was well illustrated by the relationship between the timing of seedling emergence and rainfall in our pot experiments. The expression of dormancy is modified by events during grain development, by the processes of harvesting and by the post-harvest environment. In his review of research requirements Pickett (1988) distinguished four main dormancy categories - dormancy **enforced** e.g. by soil conditions, **innate** dormancy due to seed biochemistry, dormancy

induced by weather conditions and **relative** dormancy, e.g. caused by low temperatures during critical developmental stages. He suggested that the dormancy of shed grain was likely to be an important factor in determining the numbers of volunteer seedlings in following crops.

A degree of dormancy is desirable in cereal crops to prevent pre-harvest sprouting and to maintain quality in barley (Ponton, 1992). This can result in problems during early season malting and much work has been done to develop suitable grain handling processes to overcome it, such as controlled drying regimes (Riis *et al.*, 1989). The conditions of a carefully controlled grain store, however, are the antithesis of the environment experienced by shed grain and in practice the shed seeds may well be affected by more than one cause of dormancy. Pressures on farmers to harvest early may result in shed grain containing both immature and mature seeds, conditions may have been cool during ripening, post-harvest soil moisture may be inadequate and the particular genotype may have genetically controlled mechanisms which condition a long period of innate dormancy. It would be perfectly understandable if simple laboratory tests for post-harvest dormancy carried out under controlled conditions overestimated germination and seedling emergence in pots outdoors. The opposite was the case and we conclude that post-harvest dormancy, as expressed in the standard laboratory germination tests recommended by the Institute of Brewing and official seed testing stations, is not a useful guide to dormancy, seed germination or seedling emergence in the soil after harvest. The vigour of seedling growth is critical to emergence in autumn, particularly from depth, while seed viability has a major effect on survival in soil over winter and beyond. Our results suggest that these two factors may be of much more importance than post-harvest dormancy in determining levels of volunteer barley populations in cereal rotations.

Table F1. Maximum % seedling emergence in autumn of barley seeds sown at different depths after harvest (mean across cultivars)

Harvest year	Expt. No.	Crop	Sowing depth (cm)		
			3	11½	20
1988	I	WB	23	-	0
	II	WB	20	-	0
1989	III	WB	76	-	0.1
	IV	WB	93	-	0.2
	V	SB	78	-	0
1990	VI	WB	93	10	0.1
	VII	SB	70	30	0.4
1991	VIII	WB	65	11	0.3
	IX	SB	80	7	0.2

Table F2. Phasing of emergence of volunteer barley seedlings from 3 cm sowing depth (mean across cultivars)

Harvest year	Expt No.	Crop	Sowing date	Number of days from sowing to: first emergence	peak emergence	first 4mm rainfall
1988	I	WB	24 July	7	10	4
	II	WB	5 Aug	7	21	3
1989	III	WB	2 Aug	14	19	6
	IV	WB	10 Aug	6	11	4
	V	SB	25 Aug	9	17	1
1990	VI	WB	27 July	11	27	19
	VII	SB	5 Sept	9	37	15
1991	VIII	WB	15 Aug	7	11	1
	IX	SB	20 Aug	13	31	26

Table F3. Effect of cultivar on seedling emergence in autumn of winter barley from two depths

Cultivar	1990 % emergence				1991 % emergence			
Date	22 Aug		11 Sept		29 Aug		16 Oct	
Depth (cm)	3	11½	3	11½	3	11½	3	11½
Marinka	70	13	97	19	78	18	87	19
Gaulois	39	7	91	11	49	15	59	18
Halcyon	38	2	96	5	34	6	42	8
Pastoral	21	3	89	9	35	1	59	2
Magie	10	5	93	7	63	7	77	9
Pipkin	38	5	93	6	-	-	-	-
S.E.D.	11.2		3.0		3.6		4.3	
Sig. of effect								
Cultivar	**		**		***		***	
Depth	***		***		***		***	
Interaction	NS		*		***		***	

* 5%
** - Effect significant at the 1% level NS - Not significant
*** 0.1%

Table F4. Effect of cultivar on seedling emergence in autumn of spring barley from two depths

Cultivar	1990 % emergence				1991 % emergence			
Date	2 Oct		24 Oct		23 Sept		16 Oct	
Depth (cm)	3	11½	3	11½	3	11½	3	11½
Golden Promise	54	7	79	20	36	2	86	2
Doublet	51	7	84	47	40	10	87	13
Triumph	48	5	86	31	37	6	79	7
Klaxon	43	8	63	44	20	11	79	11
Natasha	36	2	71	17	61	5	85	6
Digger	17	4	33	17	15	3	62	4
S.E.D.	6.8		4.8		9.7		7.4	
Sig. of effect								
Cultivar	**		***		*		NS	
Depth	***		***		***		***	
Interaction	*		***		*		NS	

* - Effect significant at the 5%
** - Effect significant at the 1% level
*** - Effect significant at the 0.1%

NS - Not significant

Table F5. Fate of barley seeds sown in autumn at different depths (mean across cultivars)

Harvest year	Depth sown (cm) in autumn	% not producing seedlings in autumn	% live and ungerminated when excavated	% germination thereafter in soil after 8 weeks (3 cm depth)	% germination thereafter in laboratory* after 19 days (water only)	% germination thereafter in laboratory* after 31 days (water + GA)
1988	3	79	39	2.20	-	-
	20	100	31	1.70	-	-
1989	3	20	0.15	0.014	-	-
	20	>99	0.74	0.017	-	-
1990	3	18	8	0.56	-	-
	11½	80	30	4.07	-	-
	20	>99	32	2.80	-	-
1991	3	27	8	-	1	7
	11½	91	21	-	3	20
	20	>99	18	-	2	16

* germinated on filter paper, with the addition of water only for 19 days, then with water + GA for 13 days.

Table F6. Duration of post-harvest dormancy in stored barley seeds (mean across cultivars) as demonstrated by the Germinative Energy Test.*

Harvest year	Expt. No.	Crop	Date of harvest	Starting date of germination tests and % germination							
				Date	%	Date	%	Date	%	Date	%
1988	I	WB	22 Jul	1 Nov	82	30 Nov	94				
	II	WB	4 Aug	1 Nov	85	30 Nov	97				
1989	III	WB	1 Aug	5 Aug	73	9 Sep	99				
	IV	WB	9 Aug	12 Aug	70	2 Sep	88				
	V	SB	24 Aug	26 Aug	41	23 Sep	99				
1990	VI	WB	26 Jul	27 Jul	14	10 Aug	38	31 Aug	88	12 Oct	96
	VII	SB	3 Sep	7 Sep	22	21 Sep	67	5 Oct	77	16 Nov	97
1991	VIII	WB	13 Aug	16 Aug	11	30 Aug	34	20 Sep	35	1 Nov	67
	IX	SB	20 Aug	24 Aug	37	7 Sep	73	28 Sep	74	8 Nov	94

* 100 seeds are germinated at 20°C in a 9 cm dish with 4 ml water and counted at 3 days.

Table F7. % laboratory germination after 3 days from 10 Aug of winter barley cultivars harvested 26 July 1990

	Overall effects of laboratory variables					
Cultivar	Temperature		Illumination		Water	
	18°C	10°C	Dark	Light	4 ml	8 ml
Gaulois	34	34	45	22	55	12
Halcyon	23	35	39	18	51	6
Magie	46	45	56	36	72	19
Marinka	42	47	57	32	70	19
Pastoral	13	27	32	8	27	14
Pipkin	51	54	67	39	76	30
S.E.D. ±						
Columns	4.4		4.4		4.6	
Rows	4.4		4.4		4.9	

Sig. of effect of main factors		Sig. of effect of interactions	
Cultivar	III	Cultivar x Temperature	NS
Temperature	*	Cultivar x Illumination	NS
Illumination	***	Cultivar x Water	***
Water	***	Temperature x Illumination	**
		Temperature x Water	NS
		Illumination x Water	***

*, **, *** - Effect significant at the 5%, 1% or 0.1% level

NS - Not significant.

Table F8. % laboratory germination after 3 days from 21 Sept of spring barley cultivars harvested 3 Sept 1990

Cultivar	Overall effects of laboratory variables					
	Temperature		Illumination		Water	
	18°C	10°C	Dark	Light	4 ml	8 ml
Digger	34	54	55	44	68	31
Doublet	23	54	49	43	65	27
G. Promise	46	88	90	85	95	80
Klaxon	42	65	69	57	89	37
Natasha	13	51	46	53	72	27
Triumph	51	38	33	30	46	17
S.E.D. ±						
Columns	4.4		4.4		3.9	
Rows	4.4		4.4		3.2	

Sig. of effect of main factors		Sig. of effect of interactions	
Cultivar	***	Cultivar x Temperature	NS
Temperature	**	Cultivar x Illumination	NS
Illumination	*	Cultivar x Water	***
Water	***	Temperature x Illumination	NS
		Temperature x Water	NS
		Illumination x Water	**

*, **, *** - Effect significant at the 5%, 1% or 0.1% level

NS - Not significant.

Table F9. Relationship of immediate post-harvest laboratory germination tests to seedling emergence in autumn in pots (mean across cultivars)

Harvest year	Expt No.	Crop	Laboratory tests - % germination				Pot tests - % seedlings
			GE	GC	WS	Revised	produced from 3 cm depth
1989	III	WB	73	84	65	-	76
	IV	WB	70	82	48	-	93
	V	SB	41	72	38	-	78
1990	VI	WB	14	22	5	-	93
	VII	SB	22	28	15	54	70
1991	VIII	WB	11	33	13	51	65
	IX	SB	37	29	56	70	80

GE - Germinative Energy. GC - Germinative Capacity. WS - Water Sensitivity.
Revised - 100 grains germinated in the dark at 10°C with 4 ml water, counted after 5 days

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