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Improving crop profitability by using minimum cultivation and exploiting grass weed ecology

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ABSTRACT

A range of controlled environment, glasshouse and small plot experiments were carried out between 2001 and 2005 to understand the cultural and environmental factors that influence black-grass seed dormancy and germination. Further field experiments, on large plots, assessed the relative importance of management and natural factors on black-grass populations.

A test was developed to determine dormancy level in black-grass seed collected in July. Controlled environment work indicated that temperature stress towards the end of seed maturation, irrespective of that during early stages of development, had the greatest impact on dormancy status. In black-grass, under field conditions, this critical timing was mid-June to mid-July. Lower seed dormancy was due to a combination of increased mean maximum (1.8°C) and mean minimum (1.4°C) temperatures over the long-term average for this period. In years with below-average temperatures, levels of dormancy were higher. It should be possible to provide regional forecasts of seed dormancy based on a relatively small number of samples.

The effect of a more-dormant population was to delay emergence of black-grass, compared to a less-dormant population by at least 6-8 weeks, even in the presence of adequate soil moisture. The more-dormant population also had a greater proportion (up to 20%) of seeds still viable in the late autumn. The conclusions on dormancy in black-grass cannot be immediately applied to other grass species. There was greater variation in dormancy in Italian rye-grass, barren brome and meadow brome than black-grass, but in some, such as Italian rye-grass and barren brome, dormancy lasted a shorter time than for black-grass.

In the field in high dormancy years and in wet autumns, black-grass populations showed delayed emergence. Drilling after 20 October resulted in significantly lower black-grass populations. If drilling before 20 October, ploughing resulted in the greatest reduction of high black-grass populations. At every site however, ploughing resulted in lower populations than discing.

In low dormancy years, black-grass was able to emerge immediately, provided sufficient moisture was available. This resulted in higher populations in the stubble and lower populations in the crop when assessed before the post-emergence spray. For any given cultivation regime there were no significant differences between before/after 20 October drilling dates. However, if drilling before 20 October, ploughing resulted in significantly lower black-grass populations than discing before drilling or direct drilling. There was however a consistent trend – with discing, there were fewer black-grass present in the crop where cultivation took place immediately after harvest than before drilling. The long-term trials showed that management of black-grass populations was enhanced by the use of dormancy information, but the presence of a mixed grass-weed population made black-grass management more difficult.

SUMMARY

Most black-grass seeds are shed prior to harvest of winter cereal crops, and most seeds have a degree of innate dormancy, which prevents them germinating immediately. However, this innate dormancy is relatively weak (compared with many other weeds) and, given favourable conditions, many seeds can germinate in the autumn from August to November. This period coincides with the sowing of winter cereals, so some seeds germinate prior to sowing, while others germinate within the crop. Delayed drilling of autumn-sown crops is more successful in reducing black-grass populations in the crop in some years and not others. Seedlings emerging prior to drilling can be destroyed easily by cultivations or use of a non-selective herbicide, while those emerging within the crop require application of selective herbicides.

The project aimed to determine the most cost-effective way to maximise the proportion emerging prior to drilling by maximising loss of viable seeds between shedding and establishment of the following crop through better understanding of the agro-ecology of the weed during this critical period.

The challenge was, therefore, to make sure that weed infestations could be contained within reduced cultivation systems, without increasing the reliance on herbicides and increasing the risk of herbicide resistance.

A series of field, plot, glasshouse and controlled environment experiments were carried out between 2001 and 2005 with the following objectives:

- To understand, through laboratory, controlled environment and small plot investigations, the cultural and environmental factors which influence black-grass seed dormancy and germination, to quantify the impact on subsequent infestation levels and to develop predictive methods that can be used as tools to optimise crop management and cultivation techniques;
- To quantify, in large plots, the relative importance of management and natural factors on black-grass populations (arising from both freshly shed seed and the seedbank) as affected by dormancy, soil type, season and presence of straw;
- To integrate the results into practical guidelines to reduce cultivation and weed control costs by using an improved knowledge of population biology.

The project was divided into four main sections, understanding dormancy, the short-term experiments, the long-term experiments and the conclusions.

Understanding dormancy

A range of controlled environment, glasshouse and small plot investigations were performed. In all studies, black-grass seeds were collected by gently rubbing heads over a container so that only ripe seeds were detached. Seeds were dried and cleaned and viability assessed. Germination tests were done within seven days of collection. This process provided a robust approach to categorising the level of dormancy within an individual weed lot.

Experiments investigated effects of humidity; soil moisture; air temperature and soil moisture during the heading and seed maturation stage on seed dormancy. Further experiments identified the phase, during head development and maturation, when temperature affected seed dormancy. Seed of different dormancy levels was produced and was then used in small plot studies to observe emergence patterns under a range of scenarios including: with and without additional watering and with and without straw cover.

Black-grass seed was also collected, in July at the time of peak shedding, from 20 winter cereal fields in England between 2001 and 2004 and assessed for dormancy level. Meteorological records were collated for eight sites across England. In 2004, seed from Italian rye-grass, barren brome and meadow brome were collected and dormancy measured.

The controlled environment and glasshouse experiments showed that temperature had a greater effect on dormancy of black-grass seed than moisture, with cool treatments producing more dormant seed than hot. Moisture had a secondary effect with drier conditions reducing seed dormancy. Studies in which single environmental factors were examined under controlled conditions showed that the timing of temperature stress during plant and seed development is important. The critical period in black-grass is during the latter stages of seed maturation, irrespective of temperature conditions during head emergence and flowering (anthesis). The critical period of latter seed maturation in black-grass can be related to mid-June to mid-July in field conditions.

When this information was put into the context of field scale populations from the geographical samples collected across England, the dormancy of the seed related closely to the meteorological data collected from representative sites (Fig 1). The period studied most closely, was from 15 June to 12 July over the four years from 2001 to 2004, and showed a very close relationship to the dormancy of black-grass seed. Longer periods were looked at (spanning the whole of June and July and shorter time periods within these months) but the correlation became less clear when either early June or late July was considered.

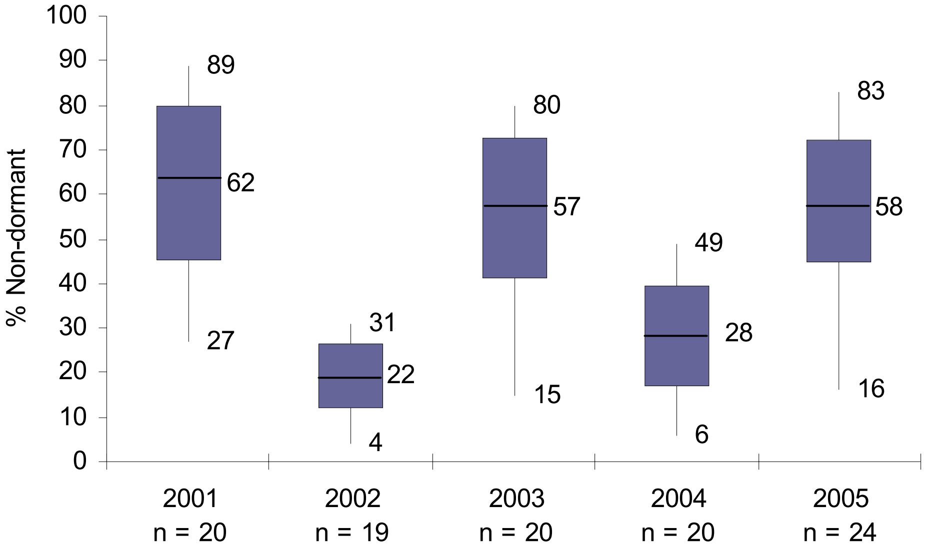


Figure 1. Proportion of non-dormant *Alopecurus myosuroides* seed collected from 19 to 24 fields in England each year from 2001-2005. The central horizontal line represents the mean, boxes encompass 50% of values and whiskers delineate the range.

From the interpretation of the weather conditions for each year, the greatest individual weather parameter affecting the dormancy of black-grass seed was temperature. The years 2001, 2003 and 2005, which had hotter than average temperatures during this critical period also, resulted in lower dormancy in the seed produced. 2002 and 2004 were both cooler years than the 30-year average and seed was more dormant. This data fitted very well with the results from the soil moisture and air temperature experiment, which indicated that temperature was the leading parameter affecting seed dormancy.

The discovery that moisture had a secondary effect in the soil moisture and air temperature experiments was not so clear cut in the natural populations. The volume of rain that fell during the critical seed maturation period was not so well related to seed dormancy as the number of days over which that rain fell. This is presumably because hot and apparently dry years, such as 2003 and 2005, can have a few stormy days where a great deal of rain may fall, skewing the rainfall volume data, whilst the rest of the period may be dry and hot. Looking at hours of sunshine and solar radiation in conjunction with rainfall can add information as to the likeliness that days were frequently overcast with light rainfall, or clear and sunny with intermittent heavy showers. In the latter case evapo-transpiration would be enhanced and the overall effect would tend towards a hot and dry period. The cooler and more overcast years of 2002 and 2004 resulted in greater seed dormancy than the hotter and sunnier years of 2001, 2003 and 2005.

The dormancy of additional grass species (Italian rye-grass, barren brome and meadow brome) from the summer of 2004 was examined to see if there was any comparison with black-grass seed dormancy.

There were fewer samples than for black-grass, but the percentage non-dormancy was much more variable in each case when germinated within two weeks of collection (Fig 2.). Two months after collection both the Italian rye-grass and barren brome samples had lost some of their dormancy and there was less variation within the samples. Italian rye-grass is a cultivated grass species and therefore derived from commercial cultivars bred to vary in dormancy. Barren brome and meadow brome are self pollinating which tends to lead to greater genetic diversity between discreet populations and this may affect dormancy. It is also notoriously difficult to determine when the seeds of brome species are ripe, so with different technicians collecting the seed from around the country there is increased potential for variation in seed ripeness. This in turn will lead to greater variability in the percentage dormancy of the samples.

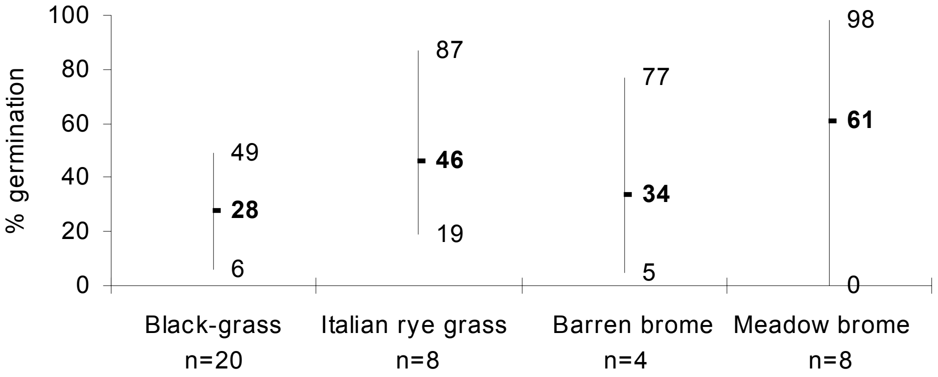


Figure 2. Percent germinated seed of additional species and black-grass within seven days of collection from geographical sites in 2004.

The microplot trial tested dormancy determined in the laboratory, under field conditions. Of the black-grass populations sown, the clearest effects were shown by seeds derived from the cool wet (CW) and hot wet (HW) treatments of the microplot experiment. The greater seed dormancy of the CW treatment carried through to plant emergence in field conditions. The CW seeds were slower to emerge than the HW treated seeds, with approximately 6-8 weeks delay in plant emergence patterns. The HW treated seeds rapidly emerged after sowing (Fig 3). The delay in emergence due to dormancy status of black-grass seed was very slightly reduced by watering, as watered seeds of both the HW and CW treatments were more advanced than their un-watered replicates.

As only approximately a quarter of the seeds sown on the microplot trial were accounted for through emergence counts, the topsoil was removed from the plot and the remaining black-grass seeds extracted. More seeds were recovered from the CW plots than the HW, but this was to be expected, as there had been fewer seeds accounted for through emergence counts. For both populations the percent recovery (including emerged seeds) was approximately 60 percent of the original seed sown, which was an excellent recovery when taking into account losses through predation and seed death. Of the recovered seed that had viable caryopses 96 and 97 percent germinated in the incubator for CW and HW treatments respectively. This indicates that the majority of the seeds remaining in the soil are still viable, irrespective of the treatment, and will stay dormant until conditions become favourable to them. For the HW treatment this amounts to approximately 10 percent of the original seed and for the CW treatment it is as much as 20 percent of the seed burden. Potentially this could have implications for spring-sown crops. Where dormancy is high there are likely to be more viable but un-germinated seed in the spring which could be stimulated to grow by spring cultivations. Field reports in 2005 suggest that there was a 'good' flush of black-grass in early spring sown crops and this may have been due to the black-grass seed set in 2004 having relatively high dormancy.

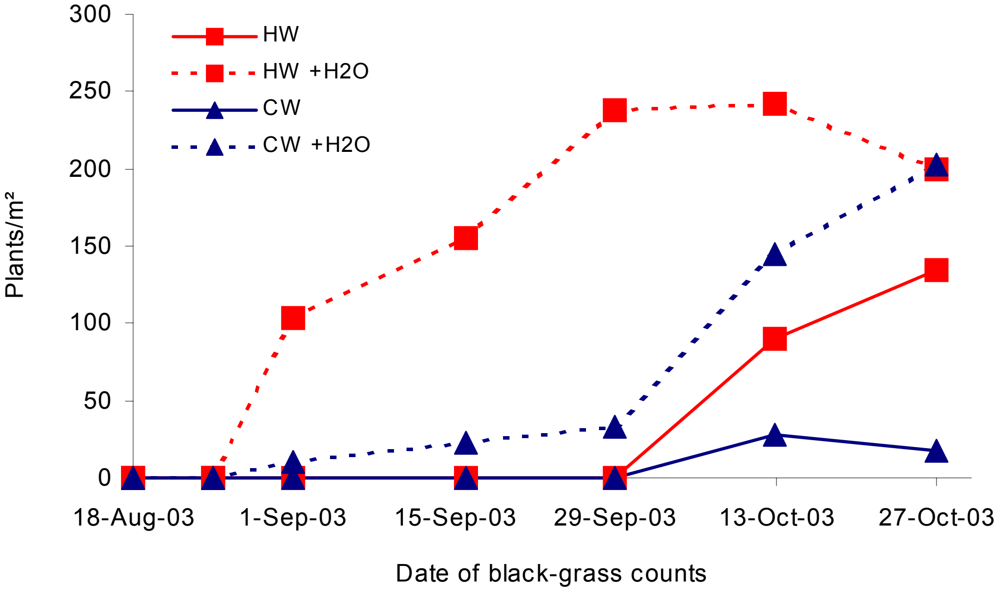


Figure 3. Selected results from the microplot trial in 2003. The Cool Wet (CW) (=Dormant) and Hot Wet (HW) (=Non-dormant) seed populations were derived from the Pot experiment. The trial plots were either watered (+H_2O), or left un-watered.

Short-term trials

The short-term trial series resulted in a wide range of environmental conditions with which to test management strategies for black-grass of different seed dormancy. A range of primary cultivation methods; plough, disc (non-inversion) and direct drilling combined with two timings of primary cultivation; immediately after harvest and up to a week before drilling and two drilling dates; early and late were investigated. Assessments were done on the seedbank, black-grass and wheat populations but the experiments were not taken to yield.

The seedbank data has proved to be very variable. The sampling regime used was a proven technique but too coarse to find very small differences between treatments over a relatively short period in time. The data indicated that there was a large loss of viable black-grass seeds over the winter period but high populations of black-grass seed survive into the spring. High seedbank populations were always associated with higher in-crop populations of black-grass.

To aid interpretation of the results, sites have been grouped into categories: black-grass dormancy level, and total rainfall during August and September. At high dormancy sites, black-grass had less than 50% of seeds with the capacity to germinate immediately (dormant), conversely low dormancy sites had black-grass with more than 50% of seeds that will germinate immediately (non-dormant). The total rainfall received in August and September was selected as a method of grouping as it reflects the conditions for black-grass germination after shedding, the level of black-grass seed dormancy and drilling date. High rainfall (wet) sites were those that received more than 100 mm during these months and low rainfall (dry) sites less than 100 mm.

Dormancy was an important factor influencing black-grass populations in the stubble immediately after harvest. When dormancy was low, in a wet autumn (2001) plant emergence was rapid, and black-grass plants could be seen in the crop prior to harvest. In a very dry year, but with low dormancy, (autumn 2003) plant emergence was delayed until significant rainfall occurred; this was also seen at both sites of the long-term trial. The most important question was when does dormancy break and black-grass free to germinate? The microplot trials at Rothamsted showed that seeds from a known more-dormant population were slower to germinate than the less-dormant seeds with a 6-8 week delay even in the presence of adequate water. Results from the short-term trials do indicate that dormancy has broken to some extent by the time of drilling as this count falls between 6-11 weeks after harvest. Observations from spring 2005 indicated that there was a spring-flush of black-grass. The experiments have shown that all black-grass has some level of dormancy and plant emergence of freshly shed seed can occur from before harvest through to a spring-flush.

Black-grass will germinate on the soil surface without the need for cultivation. The results showed that cultivations decreased the amount of black-grass that emerges before drilling. The most interesting effects of treatment can be seen with the counts done at the time of the post-emergence herbicide application. This count reflects the burden that the post-emergence herbicides have to face; this series of experiments gave them a greater challenge as no pre-emergence herbicide was used. Overall, plough was the best primary cultivation for reducing black-grass populations to 34% of that after discing. In high-pressure black-grass situations, this advantage was even greater (66%).

Timing of primary cultivation was an important factor; the short-term experiments looked at cultivations done immediately after harvest and up to one week before drilling. Overall, discing immediately after harvest resulted in 17% less black-grass than the later timing, for ploughing this figure was 24% but the dormancy of the stocks seemed to have a large impact on these reductions. Cultivating early was only beneficial in low dormancy situations, allowing time to control black-grass with before drilling cultivations and non-selective herbicide. Consolidation of any cultivation was necessary to retain moisture.

Delaying drilling date to after 20 October resulted in significantly lower black-grass populations in high dormancy situations only. When dormancy is high and there is a need to drill early, ploughing resulted in the best reduction of black-grass populations but this was not significant (Fig 4).

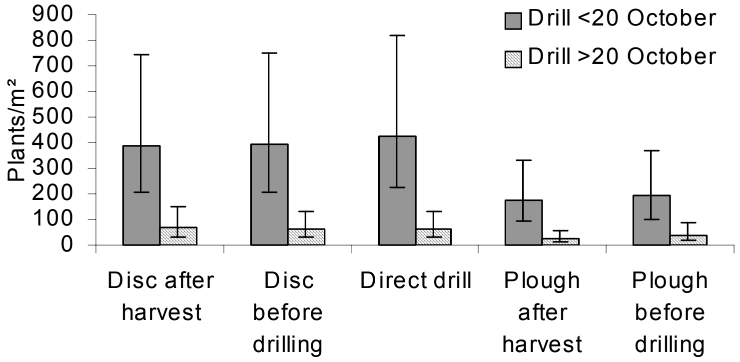


Figure 4. High dormancy: black-grass populations at the time of the post-emergence spray – drilling and cultivation effects (antilog).

In low dormancy situations, a large proportion of black-grass will germinate before drilling as long as adequate moisture was available. For any given cultivation regime there were no significant differences before or after 20 October, however, if drilling before 20 October, ploughing did result in significantly lower black-grass populations than discing immediately before drilling or direct drilling (Fig. 5).

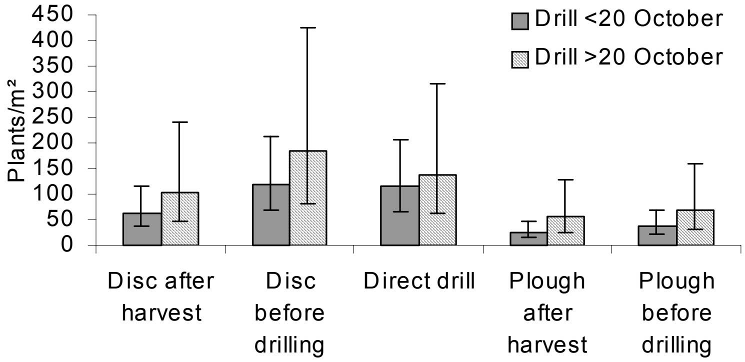


Figure 5. Low dormancy: black-grass populations at the time of the post-emergence spray –and drilling effects (antilog).

Long-term trials

The two sites of the long-term trial were located at Boxworth, Cambs and Haverholme, Lincs between 2001 and 2005. The sites were in continuous winter wheat with three treatments at each site: annual plough, a managed approach and annual minimum cultivation. Assessments of the seedbank were made in autumn and spring, black-grass plants were counted throughout the season.

The long-term trials were set up in order to manage black-grass populations over four years using the information developed within the project. The managed approach would allow the site manager to modify treatments such as cultivation method, cultivation timing and drilling date using dormancy data from the research project as it developed. The results have shown that there has been some success in applying this knowledge as it emerged. At Boxworth, black-grass populations were kept under control successfully but meadow brome and wild-oat populations increased to put the site under great pressure. Managing for black-grass alone allowed brome and other grass weeds to increase, therefore a combined strategy is needed for mixed weed populations. At the Velcourt site, black-grass management was successful until a low dormancy situation in a very dry year. Here drilling date was delayed but there had not been sufficient rainfall to encourage plant emergence of the black-grass. Plant emergence then occurred after drilling. It will always be difficult to control black-grass in situations such as this as the weather cannot be predicted, but knowledge of dormancy can help prioritise fields for drilling.

Conclusions

Dormancy

- A test was developed to determine dormancy level in black-grass seed collected in July.
- Temperature stress towards the end of seed maturation, irrespective of that during early stages of development, had the greatest impact on dormancy status. In natural black-grass populations, this critical timing was mid-June to mid-July under field conditions.
- A combination of increased mean maximum (1.8°C) and mean minimum (1.4°C) temperatures over the long-term average for mid-June to mid-July reduced the dormancy of black-grass seed. Temperature was correlated to solar radiation but negatively correlated to rainfall. Both of the years with temperatures below average resulted in higher levels of dormancy.
- Since temperature, which is consistent over large areas, is the major driver of dormancy levels in any given year, it should be possible to provide regional forecasts of seed dormancy based on a relatively small number of samples.
- The effect of a more-dormant population was to delay emergence of black-grass, compared to a less-dormant population by at least 6-8 weeks even in the presence of adequate soil moisture. The more-dormant population also had a greater number (up to 20%) of seeds still viable in the late autumn.

- The conclusions on dormancy in black-grass (20 samples per year) cannot be immediately applied to other grass species. Sampling in 2004 of a small number (up to eight samples) of Italian rye-grass, barren brome and meadow brome indicated there was greater variation in dormancy between these species but that in some, such as Italian rye-grass and barren brome, the dormancy lasted a shorter time than for black-grass. Further work would be required to be more specific in species other than black-grass.

Short-term trial

- High dormancy years

– In wet autumns with adequate moisture availability, high dormancy black-grass populations still showed delayed emergence.

– Drilling after 20 October resulted in significantly lower black-grass populations.

– If drilling before 20 October, ploughing resulted in the best reduction of high black-grass populations but this was not significant. At every site however, ploughing resulted in lower populations than discing.

- Low dormancy years

– There was no emergence of black-grass until there was adequate moisture. In small plot experiments, which were watered, we demonstrated that low dormancy populations were able to emerge immediately provided sufficient moisture was available

– Resulted in higher populations in the stubble and lower populations in the crop when assessed before the post-emergence spray.

– For any given cultivation regime there were no significant differences between before/after 20 October drilling dates, however, if drilling before 20 October, ploughing did result in significantly lower black-grass populations than discing before drilling or direct drilling. There was however a consistent trend, that for discing there were fewer black-grass present in the crop where cultivation took place immediately after harvest than before drilling

The following management matrix is an assimilation of the project findings in order to manage black-grass populations and not necessarily to maximise economic performance:

	Drilling date	
Dormancy**	Before 20 October*	After 20 October
High	**Not preferred**. When early drilling is essential, ploughing results in lowest levels of black-grass.	**Preferred.** Very much lower levels of black-grass. No difference between ploughing and discing.
Low	**Preferred**. If discing, cultivate immediately after harvest. Plough resulted in lowest levels of black-grass.	**Not preferred**. Ploughing resulted in lower levels of black-grass.

* earliest drilling date was 16 September, ** High dormancy is seed with less than 50% of seeds that will germinate immediately, Low dormancy is seed with more than 50% of seed that will germinate immediately.

Long-term trial

- Management of black-grass populations was enhanced by the use of dormancy information.
- The presence of a mixed grass-weed population made black-grass management more difficult.

1 INTRODUCTION

New EU support measures are exposing the European production of arable commodity crops to world prices. These prices are currently at an historical low and are likely to continue at this level in the medium term. This is resulting in a further intensification of autumn sown crops and the desire to reduce cultivation costs. These two factors will lead to a further increase in annual grass weed numbers, herbicide use and resistance to herbicides unless there is an improvement in the understanding of the ecology of grass weeds and this new knowledge is fully exploited.

Reducing cultivation costs provides a major opportunity towards the reduction of overall costs of production of combinable crops and can represent over 20% of the unit cost of production. However, minimum cultivations (shallow non-inversion cultivation to a maximum of 5-10 cm) run the risk of increasing grass weed infestations and herbicide resistance. Annual grass weeds are now widely seen as a major constraint in reducing costs on many farms. This was specifically identified in both the HGCA Weed Research Strategy meeting (25 January 2000) and the MAFF meeting to review priorities for weed research strategy (Clarke, 1999).

Ploughing (in comparison with minimum cultivations) primarily reduces weed infestations and has a secondary potential advantage in reducing selection pressure for resistance due to the “buffering” effect resulting from the ploughing up of older, less selected, seeds. In addition, current information suggests that where minimum cultivation is practised that a 19% higher level of control is required in the following crop to prevent populations increasing (Table 1-1). This puts greater pressure on control by herbicides, and hence increased risk of resistance, unless the opportunities to maximise weed seed loss between shedding and the establishment of the next crop are fully exploited.

Table 1-1 The % control required to contain black-grass populations under different cultivation systems and depths (Moss, 1990).

Cultivation	Depth	% control required
Tine cultivations	<5 cm (direct drilling)	97
	10 cm	95
	15 cm	93
Plough	20-25 cm	78

The challenge is to make sure that weed infestations can be contained within reduced cultivation systems without increasing the reliance on herbicides and increasing the risk of herbicide resistance.

Most black-grass seeds are shed prior to harvest of winter cereal crops, and most seeds have a degree of innate dormancy, which prevents them germinating immediately. However, at the start of this project it was known that this innate dormancy was relatively weak (compared with many other weeds) and some seeds germinated prior to sowing, while others germinated within the crop. It was also recognised that delayed drilling of autumn sown crops was more successful in reducing black-grass populations in the crop in some years and not others. Seedlings emerging prior to drilling can be destroyed easily by cultivations or use of a non-selective herbicide, while those emerging within the crop required the application of selective herbicides. The aim must be to maximise the proportion emerging prior to drilling. The project aimed to determine the most cost-effective way to achieve this through maximising the loss of viable seeds between shedding and the establishment of the following crop through a better understanding of the agro-ecology of the weed during this critical period.

Grass-weeds maturing under different environmental conditions tend to produce seeds with differing degrees of dormancy: high temperature/drought stress - lower dormancy; low temperature/wet conditions - higher dormancy. Knowledge of the weed seed dormancy status should improve decision making in relation to stubble management and crop drilling date.

Although MAFF commissioned research (Commission CE0611) explored aspects of weed population dynamics and contributed information on the biology of grass weeds, especially the brome grasses, it has not explored in detail the dormancy of black-grass, the key weed in this programme. The Weed Management Support System (WMSS) provides an ability to make strategic decisions based on current information. It has also provided a framework for the receipt of future information, including information from this project. In addition to aspects on herbicide selection pressure, a Defra-funded project on herbicide resistance (under PT0225) has evaluated the impact of reduced cultivation on the selection pressure for herbicide resistance. The aim of this project was to generate and to exploit knowledge on the weed ecology of grass weeds in order to maximise viable seed losses, both between crops and to assess the value of each management option. By knowing the role and the value of each option the farmer will be able to select with more certainty, the most cost effective basis for weed control with the machinery and resource available together with soil type and the cropping constraints.

The challenge was, therefore, to make sure that weed infestations could be contained within reduced cultivation systems, without increasing the reliance on herbicides and increasing the risk of herbicide resistance.

1.1 Objectives

1.1.1 Overall objective

To generate and exploit information on black-grass ecology to reduce production costs of combinable crops by optimising the cultivation strategy.

1.1.2 Specific objectives

1. To understand, through laboratory, controlled environment and small plot investigations, the cultural and environmental factors which influence black-grass seed dormancy and germination, to quantify the impact on subsequent infestation levels and to develop predictive methods that can be used as tools to optimise crop management and cultivation techniques;

2. To quantify, in large plots, the relative importance of management and natural factors on black-grass populations (arising from both freshly shed seed and the seedbank) as affected by dormancy, soil type, season and presence of straw;

3. To integrate the results into practical guidelines to reduce cultivation and weed control costs by using an improved knowledge of population biology.

1.2 Duration

Four years, ending on 31 August 2005.

1.3 Report structure

The report is divided into four main sections, understanding dormancy in Section 2, results from the short-term experiments in Section 3, results from the long-term experiments in Section 4 and conclusions in Section 5.

2 DORMANCY

The objectives of the dormancy studies were to understand, through laboratory, controlled environment and small plot investigations, the cultural and environmental factors, which influence black-grass seed dormancy and germination. To quantify the impact on subsequent population levels and to develop predictive methods that can be used as tools to optimise crop management and cultivation techniques.

2.1 Materials and methods

In all studies seeds were collected by gently rubbing heads over a container, so that only ripe seeds were detached. Seed were air dried for a few days in open trays in a room maintained at a constant 18°C and 65% relative humidity (RH). Before conducting viability and germination tests, samples were cleaned in an air column separator to remove most empty seeds and debris. A minimum airflow was used and checks were made to minimise loss of seeds. Viability was estimated by dissecting 50 random seeds per sample and recording the total number of caryopses present.

All germination tests were initiated within seven days of seed collection, and data was corrected before analysis to account for differences between samples in the proportion of seeds containing a caryopsis.

Germination was determined by placing 50 seeds in 9 cm Petri-dishes containing three cellulose filter papers (Whatman Number 1) covered by one glass-fibre filter paper (Whatman GF/A) and adding 7 ml KNO_3 (2 g/l in deionised water) per dish. For each sample tested, four replicate dishes were used. They were placed in sealed transparent polythene bags in an incubator with a 17°C, 14 h light and a 11°C, 10 h dark phase. The number of seeds that had germinated within two weeks were recorded and used as a measure of the proportion of non-dormant seeds in the sample. All germination data were corrected before analysis to account for differences between samples in the proportion of seeds containing a caryopsis. Analysis of variance was performed using GENSTAT.

A population is more-dormant or has high dormancy when a lower number of non-dormant seeds are present, when tested in a Petri-dish few seeds grow. A population is less-dormant or low dormancy when a large number of seeds grow in the Petri-dish test.

2.1.1 Soil moisture experiment

Experiments were done in three successive years (2001–2003) to investigate the effect of soil moisture during the heading and seed maturation phase, on the dormancy of black-grass seeds produced by plants growing in boxes. Four boxes were filled with soil and seed planted in October each year (2001, 2002 and 2003) and kept outside until the following May when black-grass heads started to emerge. All boxes were then placed in an open-sided poly-tunnel to maintain close to ambient conditions. Two boxes (‘wet’) were stood in large trays (10 cm deep) which were kept full of water in order to maintain the soil in the boxes at close to field capacity, while the other two boxes (‘dry’) were kept drought stressed by minimal watering. Soil samples were collected at regular intervals from each box and dried at 80ºC overnight to determine surface soil moisture. Black-grass seeds were collected from the plants in each box when an estimated 10%, 50% and 90% of seeds had shed. The seeds were dried, and tested for viability and germination capacity as described in Section 2.1.

2.1.2 Soil moisture and air temperature experiment

Experiments were done in three successive years (2002–2004) to investigate the effects of different air temperature and soil moisture during the heading and seed maturation phase on the dormancy of black-grass seeds produced by plants growing in pots. Black-grass plants were grown from seed in individual 5 cm pots and then transplanted at GS 22-23 into 25 cm diameter pots (five plants/pot). In May, when heads started to emerge, sets of plants were then subjected to four different temperature and moisture regimes:

- Hot-Wet (HW), pots were kept in a heated glasshouse set at 28-31°C. The soil was kept at close to field capacity by standing the pots in water filled trays.

- Hot-Dry (HD), pots were kept in the same glasshouse as above, but the soil in these pots was kept as dry as possible and given only sufficient water daily to keep the plants alive but drought stressed.
- Cool-Wet (CW) pots were kept in an open-sided poly-tunnel to maintain close to ambient temperature. The soil was kept at close to field capacity as HW pots above.
- Cool-Dry (CD). Pots were kept in the same open-sided poly-tunnel as above and the soil kept as dry as possible.

The maximum and minimum temperature in both the heated glasshouse and open-sided poly-tunnel were recorded daily. Seed was collected when an estimated 10%, 50% and 90% had shed, air dried, and tested for viability and germination capacity as described in Section 2.1.

2.1.3 Timing of temperature stress experiment

The objective was to identify in which phase, during head development and seed maturation, temperature affected seed dormancy. Four environmental treatments were used, these were designated: Hot-Hot (HH); Hot-Cool (HC); Cool-Cool (CC); and Cool-Hot (CH). Four plants in each of two replicate pots were subjected to each of the four environmental treatments. The earlier phase was imposed during head emergence and flowering and the later phase imposed during seed maturation. Two controlled environment cabinets were used, the 'Hot' cabinet providing a 28ºC, 16 h day and 16ºC, 8 h night and the 'Cool' cabinet an 18ºC, 16 h day and 12ºC, 8 h night. Light levels were set at 850 μmol/m^2/s PAR (Photosynthetically Active Radiation) in both cabinets.

Black-grass plants were grown from seed in individual 5 cm pots in a glasshouse and then transplanted on 2 December 2003 into 20 cm diameter pots (four plants/pot). For treatments see Table 2-1. CH plants were transferred to the second-phase environment a week later than the HC treated plants due to the cooler initial conditions delaying plant development. Seed was collected from plants of each treatment when an estimated 10%, 50% and 90% had shed, air dried, and tested for viability and germination capacity as previously described.

Table 2-1. Timing of temperature treatments on black-grass grown in plots under controlled environment conditions.

Date	Hot – Hot (HH)	Hot – Cool (HC)	Cool – Cool (CC)	Cool – Hot (CH)
20-Dec-03	Transplanted into pots in glasshouse.	Transplanted into pots in glasshouse.	Transplanted into pots in glasshouse.	Transplanted into pots in glasshouse.
21-Jan-04	Placed in COOL cabinet.	Placed in COOL cabinet.	Placed in COOL cabinet – early and later phases.	Placed in COOL cabinet – early phase.
11-Feb-04	Plants flowering and moved to HOT cabinet – early + later phases.	Plants flowering and moved to HOT cabinet – early phase.	-	-
5-Mar-04	-	Returned to COOL cabinet at first seed shedding – later phase.	-	-
12-Mar-04	-	-	-	Moved to HOT cabinet at first seed shedding – later phase.
12-Mar-04 to 5-Apr-04	Seed collections at estimated 10%, 50% and 90% shedding.	Seed collections at estimated 10%, 50% and 90% shedding.	Seed collections at estimated 10%, 50% and 90% shedding.	Seed collections at estimated 10%, 50% and 90% shedding.

HOT – 28°C, 16 h day and 16°C, 8 h night, COOL - 18°C, 16 h day and 12°C, 8 h night. Light levels were set at 850 µmol/m²/s PAR for both HOT and COOL.

2.1.4 *Humidity experiment*

Seed collected from natural black-grass populations at Rothamsted in 1999 were sown in controlled environment cabinets. At GS 22-23, five seedlings were potted into a 25 cm pot, filled with Kettering loam. Four replicate pots were set up for each humidity level. Two weeks after setting up, the cabinet environment was adjusted for vernalisation to 10ºC, 10 h day and 4ºC, 14 h night. On the completion of vernalisation, after four weeks, the conditions were changed to 17ºC, 14 h day and 8ºC, 10 h night. After a further two weeks humidity stresses were imposed. The high humidity cabinet was set at 90-95% RH and the low at 65% RH. Both cabinets had a 20ºC, 16 h day and 15ºC 8 h night. Once the plants had developed and produced seed, the seed was collected when 30% and 70% seed had shed. The seed was air dried and tested for viability and germination capacity as previously described in Section 2.1.

2.1.5 *Geographical samples*

Black-grass seeds were collected from 20 winter cereal fields in England each year between 2001 and 2004 (19 sites in 2002). The fields were chosen to give a good geographical distribution across the country (Figure 2-1). Seeds were collected mainly in July each year at peak time of seed shedding, when about 50% of seeds had been shed. Samples were air dried before sending to Rothamsted for germination testing which, where possible, was initiated within seven days of seed collection.

Meteorological records were collated for eight recording centres across England, representative of the 79 seed sample collection sites between 2001 and 2004 (Figure 2-1). The recording centres were Rothamsted Research, Harpenden (Hertfordshire), The Arable Group, Morley (Norfolk) and six ADAS sites; Boxworth (Cambridgeshire), Drayton (Warwickshire), Gleadthorpe (Nottinghamshire), High Mowthorpe (North Yorkshire), Rosemaund (Herefordshire), and Terrington (Norfolk). The meteorological parameters used were maximum and minimum daily temperatures (°C), daily rainfall (mm), and where available, daily sunshine (h) and daily radiation (MJ/ m^2). For comparative purposes, 30 year means (1975-2004) have been used for all recording centres.

2.1.5.1 Additional Species

In 2004, additional money was received from Home-Grown Cereals Authority (HGCA) to assess dormancy in other grass species. In addition to black-grass, seed samples were also collected from eight sites for Italian rye-grass (Lolium multiflorum), four sites for Barren brome (Anisantha sterilis) and eight sites of meadow brome (Bromus commutatus). Samples of the seeds were germinated within seven days of collection using the standard Petri dish germination method. The remaining seeds were stored at 18ºC and at 65% RH until September 2004 before germinating to see it there was any further effect on seed dormancy.

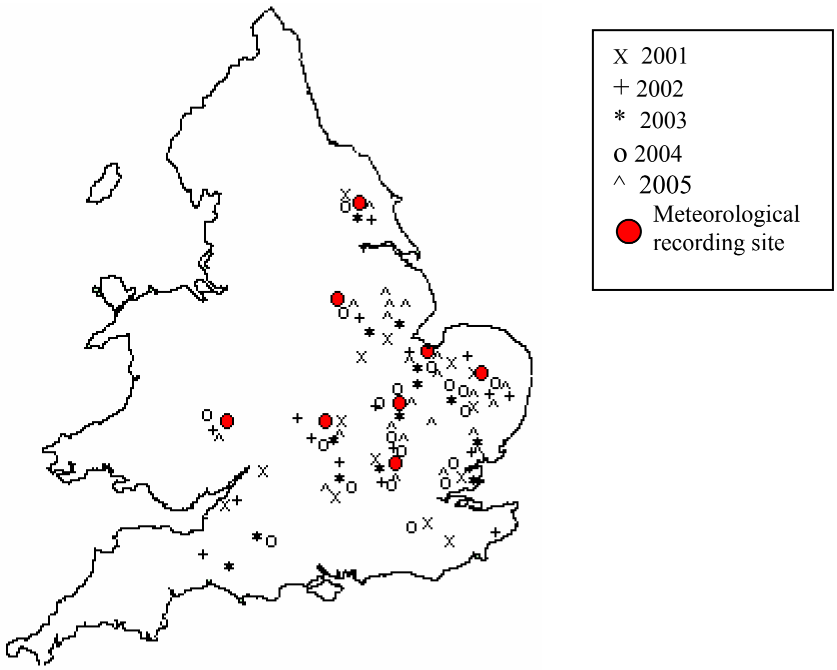


Figure 2-1. Location of geographical sample black-grass seed collection sites 2001–2005 and meteorological recording sites.

2.1.6 Microplots

Field experiments were done in 2003 and 2004 to determine to effects of seed dormancy on plant emergence in the field. Micro-plots, each 50 x 50 cm, were set up on an uncultivated, weed-free winter wheat stubble at Rothamsted, and black-grass seeds were surface-sown (500 per plot, equivalent to 2000 seeds/m²) on 12 August 2003 and 1 September 2004. Each experiment comprised a randomised block design with two populations in four replicates (2003) and six replicates (2004), (Table 2-2). The seed populations were from the cool-wet (CW) and hot-wet (HW) treatments from the soil moisture and air temperature experiment (Section 2.1.2). Seeds were kept in a seed store maintained at a constant 18°C and 65% RH between collection and sowing.

Half of the plots were additionally watered to ensure that plant emergence was not restricted by insufficient soil moisture. These plots were watered when the soil surface appeared dry, by applying 2.5 l of water per plot (equivalent to 10 mm rainfall) using a watering can fitted with a fine rose. The autumn of 2003 was particularly dry (Table 2-3) so plots were watered almost daily between 12 August 2003 and 24 October 2003 (total of 145 l water per plot). The autumn of 2004 was much wetter, so less additional watering was needed and it was not necessary to water beyond 29 September 2004 (total of 45 l water per plot). Watering of all other plots was by natural rainfall. Black-grass plants were counted on all plots every 14 days until 13 January 2004 (watered plots were not counted after 11 November 2003), and 25 November 2004.

Table 2-2. Populations of black-grass sown on the micro-plot experiments in 2003 and 2004, identifying those which were un-watered and watered.

2003 Sowing date 12-Aug-03		2004 Sowing date 1-Sept-04	
Un-watered	Watered	Un-watered	Watered
CW	CW	CW	CW
HW	HW	HW	HW

Table 2-3. Mean daily rainfall at Rothamsted, for August-October 2003 and 2004 (mm).

Year	August	September	October	Total
2003	0.1	0.5	1.2	2.7
2004	3.7	0.8	4.1	8.6

2.1.7 *Straw experiment*

A small plot experiment was done in 2002 to 2003, and investigated the effect of chopped straw, cultivations and watering on black-grass plant emergence in the field. Plots were 3 x 12 m with two 1.5 x 2 m sub-plots arranged centrally (2 m apart, 3 m from the plot ends and 0.75 m from the edge) over four replicates. The sub-plots corresponded to different black-grass populations (Table 2-4). The dormancy of the seed populations had previously been assessed in Petri dishes.

Table 2-4. Black-grass seed populations sown on the Straw experiment 2002 and 2003.

Population	2002	2003
Less dormant	LARS’95	ROTH’02
More dormant	ROTH’02	ROTH’03

Black-grass seeds were sown within a quadrat marking the sub-plot area, and sprinkled through a flowerpot to distribute them evenly (Table 2-5). Plots were sprayed off with glyphosate in 2002, but not in 2003 as there was no plant emegence before the straw was applied. The sub-plots were treated with or without chopped straw (@ 2.25 kg/plot, equivalent to 5 tonnes/ha), with or without tine cultivations to 5 cm (two passes with tines and one with the Roterra), and with or without watering (@ 30 l/plot, equivalent to 10 mm rainfall, 2002 only). Plots were watered using a tank mounted on the tractor and a glasshouse spray rose. A rain gauge was used to check the amount of water applied. Black-grass and winter wheat emergence were assessed fortnightly.

Table 2-5. Straw experiment field diary for sowing and treatments.

	2002	2003
Black-grass seeds sown	30-Jul-02 (@ 1250 seeds/m^2)	16-Jul-03 (@ 2000 seeds/m^2)
Crop harvested	17-Aug-02	6-Aug-03
Straw applied (@ 5 tonnes/ha)	28-Aug-02	12-Aug-03
Plots watered (equivalent to 10 mm rainfall)	02-Oct-02 09-Oct-02	Not applied
Tine cultivated to 5cm	04-Sept-02	15-Aug-03

2.2 Results and relevant data

2.2.1 Soil moisture experiment

The proportion of non-dormant seeds produced under wet soil conditions was slightly lower than under dry conditions in 2001 and 2002, but the opposite trend occurred in 2003 (Figure 2-2). With both soil moisture treatments, the proportion of non-dormant seeds was significantly ($P<0.05$) lower in 2002 than in 2001 and 2003. This was consistent with the results found for the geographical sampling from many fields in those years (2.2.5), and was probably a consequence of different temperatures during seed maturation.

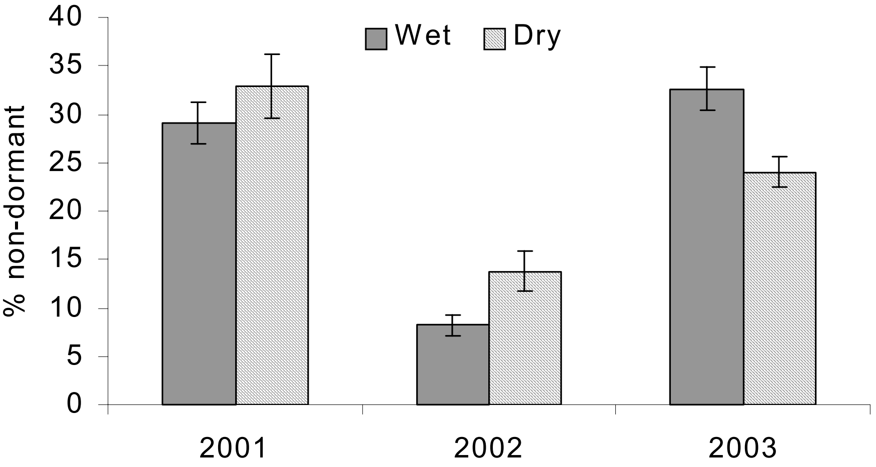


Figure 2-2. Percent non-dormant black-grass seed following watering and drought stress of seeds produced in the soil moisture experiment.

2.2.2 *Soil moisture and air temperature experiment*

Temperature had a greater effect on dormancy than soil moisture (Figure 2-3). Hot growing conditions produced significantly more non-dormant seed than cool. Under hot conditions, 71-92% non-dormant seed were produced compared to 6-43% non-dormant seeds from cool conditions. There was an effect of moisture seen; dry conditions encouraged greater non-dormancy than wet. HD conditions produced 78-92% non-dormant seed compared to 71-75% for HW. Similarly, CD conditions produced 26-43% non-dormant seed compared to 6-31% for CW.

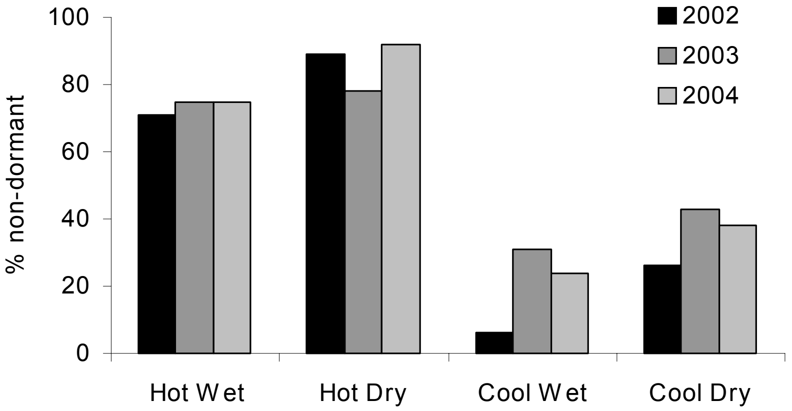


Figure 2-3. Percent non-dormant seed produced following temperature and moisture stresses during plant and seed development of black-grass (Hot = 28-31ºC, Cool = 18-21ºC, Wet = field capacity and Dry = kept as dry as possible whilst still keeping the plants alive).

2.2.3 *Timing of temperature stress*

Temperature had the greatest effect on seed dormancy during latter seed maturation and there was no effect of temperature on seed dormancy during the early stages of growth (Table 2-6). The HH treated plants produced seed with an average of 75% non-dormant and the CH, 76% non-dormant. This was compared to 48% and 49% non-dormant seed for the CC and HC treatments respectively. The percentage non-dormant seed was consistent across the three seed collection timings.

Table 2-6. Percent non-dormant seed of black-grass following timing of temperature stresses.

Treatment	% Non-dormant seed 10% seed shed	50% seed shed	90% seed shed	Mean across timings
Hot Hot (HH)	79	71	76	75
Cool Hot (CH)	61	87	79	76
Cool Cool (CC)	43	47	54	48
Hot Cool (HC	53	36	59	49
		S.E. ± 5.31		S.E. ± 3.07
Mean across temperature treatments	59	61	66	S.E. ± 2.65

Hot = 28°C, 16 h day and 16°C, 8 h night. Cool =18°C, 16 h day and 12°C, 8 h night. Movement between treatments was at first seed shedding, relating to mid-June in the field.

2.2.4 *Humidity experiment*

There was a greater level of non-dormancy of the seed produced under low humidity (65% RH) conditions, than those produced under high humidity (95% RH) conditions (*P<0.05,* Table 2-7). There was no significant difference between the timing of seed collection at 30% seed shed and 70% seed shed.

Table 2-7. Percent non-dormant seed produced from black-grass plants grown under controlled humidity conditions.

Collection timing (% seed shed)	High Humidity (95% RH) 30 %	70 %	Low Humidity (65% RH) 30 %	70 %
Mean % non-dormant seed (corrected for viability)	70.5	61.4	75.5	82.5
Mean	65.9% S.E. ± 2.19		78.3% S.E. ± 2.83	

2.2.5 *Geographical samples*

Seed collected in 2001, 2003 and 2005 showed a much higher percent non-dormancy than that collected in 2002 and 2004 (Figure 2-4), with average non-dormancy of 62%, 57% and 58% compared to 22% and 28% respectively. The mean proportions of non-dormant seeds for the samples collected in each of the five years, with their standard errors, were respectively: 2001 62% ± 4.4; 2002 22% ± 3.7; 2003 57% ± 4.6; 2004 28% ± 3.0; 2005 58% ± 3.7. In 2002 there was one outlying sample from Nottinghamshire with 77% non-dormancy compared to an average of 22%, from a range of 4-31%. In 2001, 2003 and 2005 where the average percent non-dormant seed was higher, the range also increased when compared to the lower average non-dormancy and tight ranges seen in 2002 and 2004.

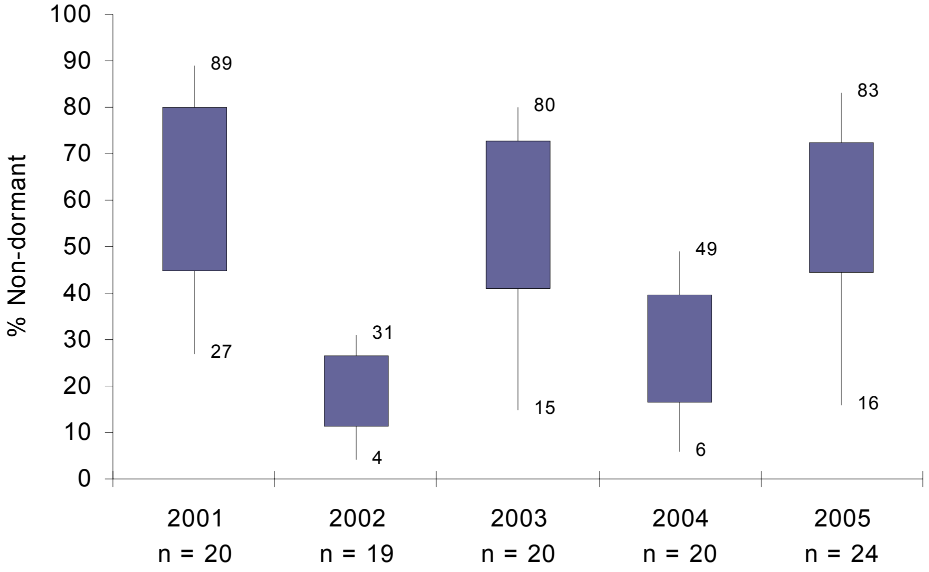


Figure 2-4. Percent non-dormancy of black-grass seed collected from 19 to 24 geographical sites each year from 2001-2005.

2.2.5.1 Additional Species

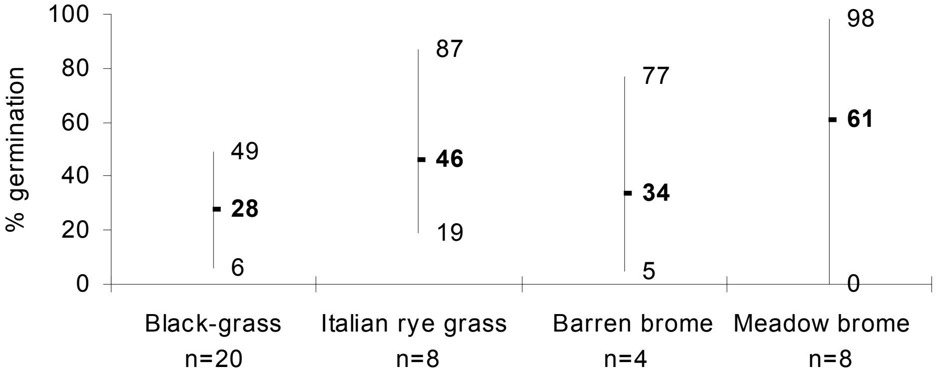


Figure 2-5. Percent germinated seed of additional species and black-grass within seven days of collection from geographical sites in 2004.

Black-grass had an average non-dormancy of 28% over quite a tight range of 6-49% non-dormant seed (Figure 2-5). Both Italian rye-grass and barren brome had a greater range of 19-87% and 5-77% respectively, but Italian rye-grass had greater non-dormancy at 46% compared to 34% for barren brome. The seed collected from meadow brome had highly variable dormancy with a range of 0-98%, but also the highest average non-dormancy of 61%.

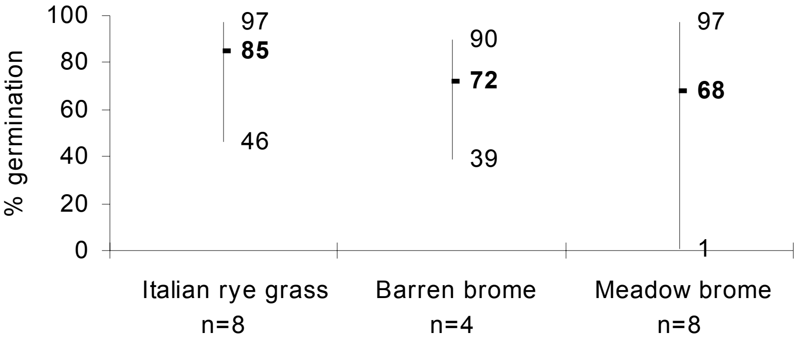


Figure 2-6. Percent-germinated seed from additional species from a germination test in September 2004, seed collected from geographical sites during the summer 2004.

The average non-dormancy for Italian rye-grass and barren brome increased from 46% and 34%, to 85% and 72% respectively when the stored seed was germinated in September (Figure 2-6). There was also a tightening in the range for both species. Meadow brome seed continued to be very variable in dormancy with a range of non-dormancy from 1% to 97% and the average percent non-dormant only slightly increased from 61% to 68% with storage.

2.2.5.2 Meteorological data

Maximum and minimum temperatures and rainfall were recorded at all eight sites. Hours of sunshine were recorded at five of the sites (High Mowthorpe, Morley, Rosemaund, Rothamsted and Terrington). Solar radiation was only recorded at Rothamsted. In 2001, 2003 and 2005, mean maximum and minimum temperatures were hotter than average (Figure 2-7). Also hours of sunshine and solar radiation were above average, although sun hours were just slightly below average in 2005. It was drier than average in 2001, but 2003 and 2005 were wetter.

In the cooler years of 2002 and 2004 the mean maximum temperature was lower than average by 0.5°C and 1.1°C respectively, mean minimum temperatures in 2002 were equal to the long-term mean but 0.8°C lower in 2004. The warmer years were in 2001, 2003 and 2005, here, mean maximum temperatures were on average 1.8°C (range 1.2 - 2.6°C) higher than the long-term average, Mean minimum temperatures were also higher by 1.4°C (range 0.5-1.9°C).

Hours of sunshine were below average for both years, although solar radiation at Rothamsted was above average. It was drier in 2002 and wetter in 2004 than the long-term mean.

High Mowthorpe, Gleadthorpe and Terrington, had much higher than average rainfall in 2003, putting the average for all sites wetter than the long-term mean. Temperatures, hours of sunshine and solar radiation were all above average, potentially increasing evaporation and transpiration and reducing water stress to the black-grass plants. Much of the rainfall fell in two days at the end of June. Gleadthorpe and High Mowthorpe received 53.7 mm and 50.4 mm rainfall respectively on 30 June 2003 (long-term June daily average being 1.6 mm and 1.9 mm at each site). Terrington was generally wetter towards the end of June without such extremes, but on 30 June 2003 received 19.7 mm of rainfall (the long-term daily average being 1.7 mm). It was also wet 22 June 2003 at Terrington and Gleadthorpe with 19.7 mm and 20.1 mm of rainfall at each site respectively. Similarly in 2005 there were a couple of days in late June and early July at a few sites where there was heavy rainfall, particularly the 28 June 2005 at Terrington where 30.0 mm of rain fell.

Between 15 June and 12 July, 10 days rain fell in 2001 and 12 days in 2003 and 2005 (Table 2-8). The number of rain days in 2002 and 2004 were 15 and 19 days respectively. It was a hot and dry summer in 2003, the number of days when rain fell was low, despite higher than average rainfall collected at the eight sites. Higher than average temperatures, hours of sunshine and solar radiation suggest that the periods between the rainfall were hot and sunny. In contrast, 2002 was cooler and less sunny but was drier than average. The number of rain-days were greater than in 2003 with an average 15.1 days of rain during the 28 day period, suggesting that the weather was generally cooler and overcast with frequent light rainfall.

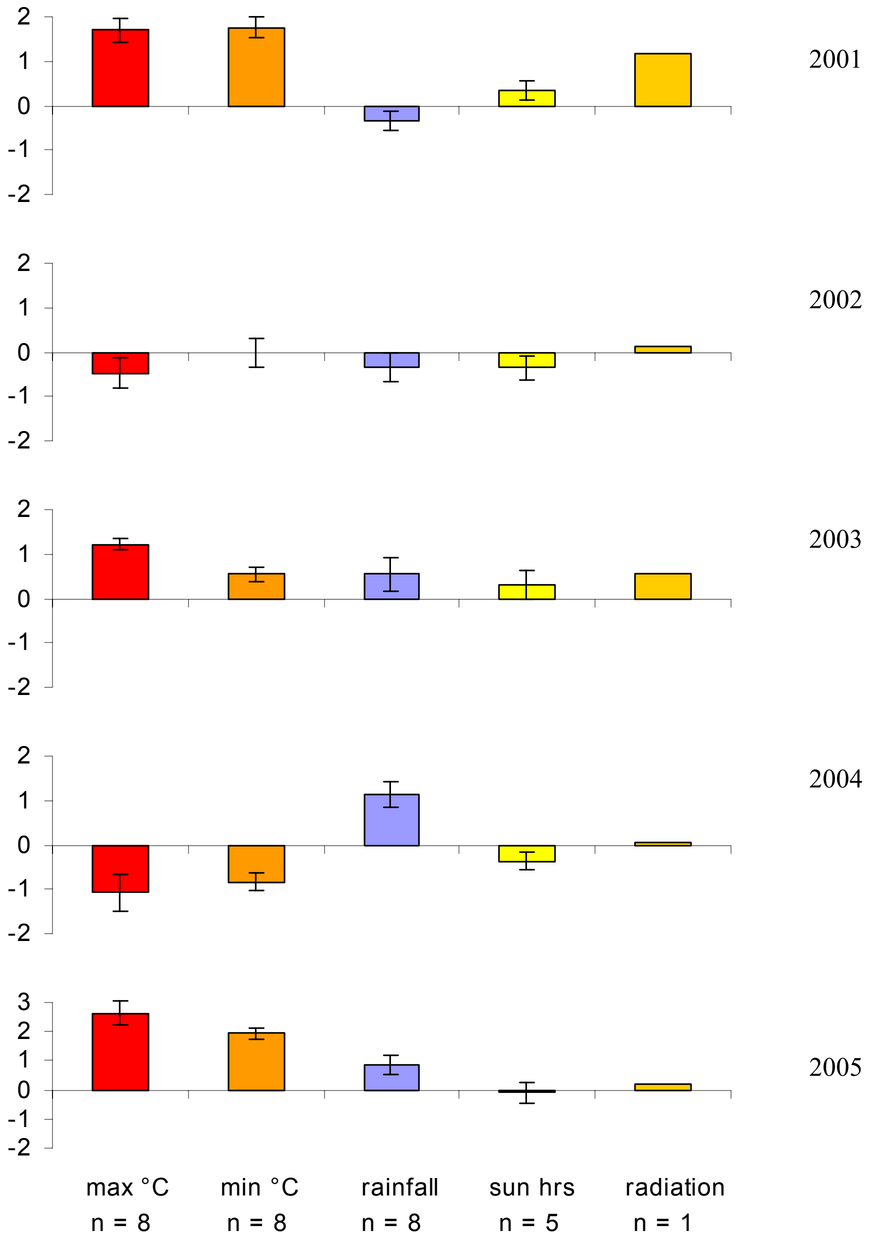


Figure 2-7. Average weather parameters from eight sites across England, for four weeks from 15 June to 12 July, 2001-2005. The y-axis scale shows difference from the long-term mean and the units are dependent on the parameter; temperature (°C), daily rainfall (mm), sunshine (h), radiation (MJ/m²).

Table 2-8. Rain-days at each meteorological recording site during the period 15 June to 12 July, 2001-2005.

	2001	2002	2003	2004	2005
Boxworth	14	No data	8	17	12
Drayton	8	13	7	17	12
Gleadthorpe	7	13	10	20	9
High Mowthorpe	7	19	12	23	No data
Morley	12	18	14	20	15
Rosemaund	9	13	9	20	10
Rothamsted	12	14	10	14	12
Terrington	11	16	12	24	11
Total	80	107	82	155	81
Average	10	15	10	19	12

2.2.6 Microplots

As in the soil moisture and air temperature experiment, non-dormancy of the HW population was greater in the field than the CW population (Figure 2-8 and Figure 2-9) as the seeds germinated more readily. In both cases watering encouraged earlier plant emergence. In 2003, the plant emergence in the un-watered plots was delayed by five to six weeks due to particularly dry autumn weather (Figure 2-8). Plant emergence in the CW watered plots was delayed by a similar time. Once plant emergence had started the HW populations were still quicker to germinate than the CW. The autumn of 2004 was wetter than 2003 and plant emergence in the watered plots was rapid, the un-watered plots were not delayed. The HW populations were less dormant than the CW (Figure 2-9). Of the 2000 seeds/m^2 sown on each plot in 2004, approximately a quarter of the seeds were accounted for through plant emergence counts. To determine the fate of the un-germinated black-grass seeds, soil samples were taken and the remaining seeds extracted.

More black-grass seeds were recovered from the CW plots than the HW plots, 93 and 58 seeds respectively (Table 2-9), but there had been more emergence on the HW plot. Overall, using emergence counts and seed recovery, 64% of the CW seed and 57% of the HW seed sown were accounted for. The percent germination of the recovered seed (when corrected for viability by caryopsis testing all un-germinated seed) was 96% for CW and 97% for HW plots. Despite CW seed having greater non-dormancy than HW, resulting in fewer seeds germinating during the autumn, the persistence of viable seed was unaffected by the cool or hot treatments.

Table 2-9. Black-grass seeds recovered from soil samples taken from the Microplot experiment 2004 (values meaned from six reps).

Treatment	Highest plant count on plot/0.1m^2.	Seed no. recovered from soil sample/0.1m^2	% original seed accounted for.	Recovered seed	
				Total no. of germinated seed.	% germination (corrected for caryopsis present)
CW	35	93	64	75	96
HW	55	58	57	45	97

Cool Wet (CW) and Hot Wet (HW) populations originated from seed collected from the pot experiment. Samples were from watered plots on the field trial.

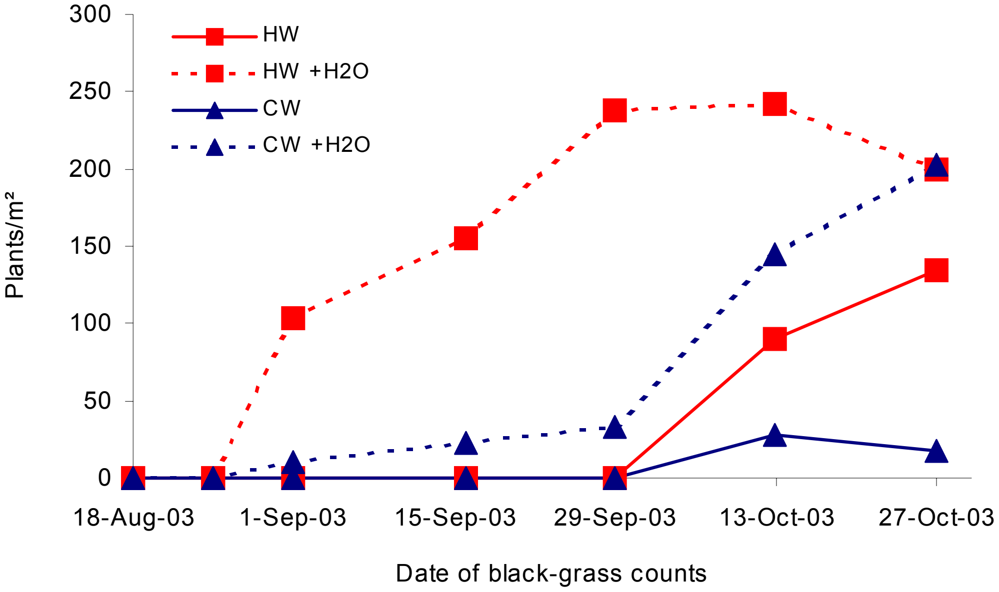


Figure 2-8. Selected results from the Microplot Trial in 2003. The Cool Wet (CW) (=Dormant) and Hot Wet (HW) (=Non-dormant) seed populations were derived from the Pot experiment. The trial plots were either watered (+H_2O), or left un-watered.

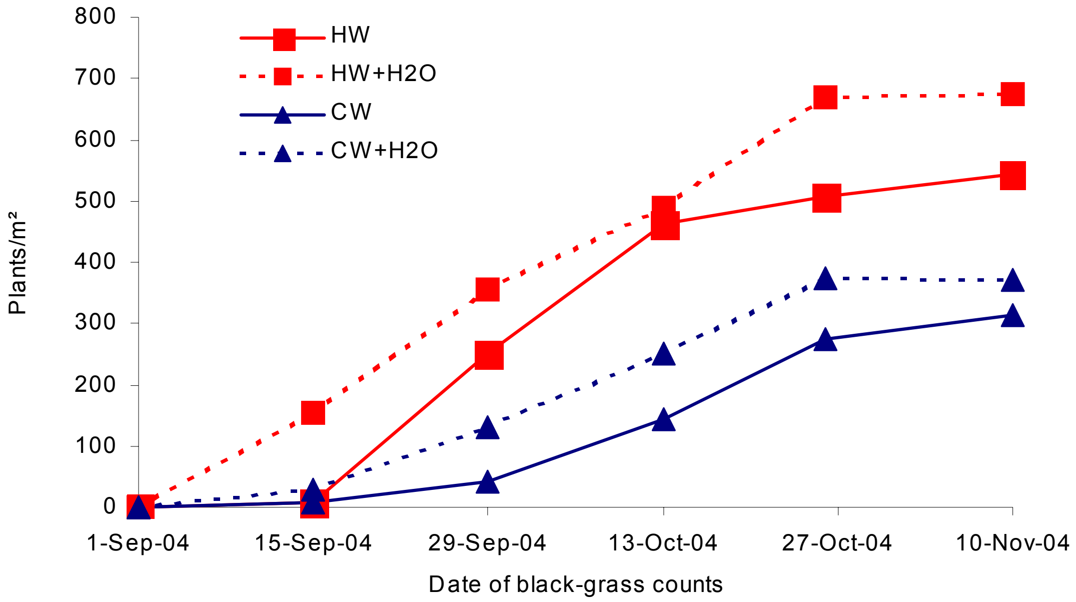
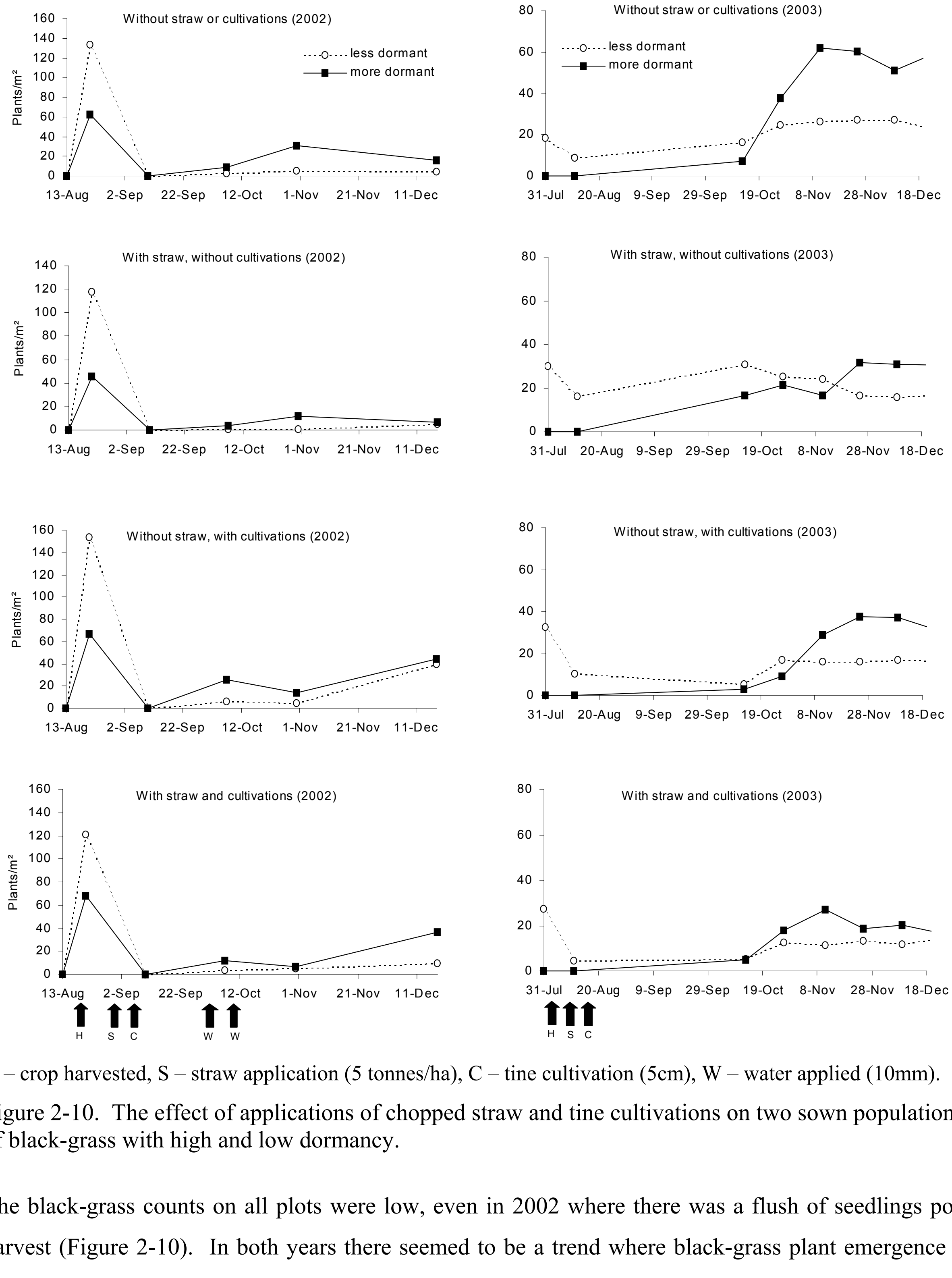


Figure 2-9. Selected results from the Microplot Trial in 2004. The Cool Wet (CW) (=Dormant) and Hot Wet (HW) (=Non-dormant) seed populations were derived from the Pot experiment. The trial plots were either watered (+H_2O), or left un-watered.

2.2.7 Straw plots experiment



H – crop harvested, S – straw application (5 tonnes/ha), C – tine cultivation (5cm), W – water applied (10mm).

Figure 2-10. The effect of applications of chopped straw and tine cultivations on two sown populations of black-grass with high and low dormancy.

The black-grass counts on all plots were low, even in 2002 where there was a flush of seedlings post harvest (Figure 2-10). In both years there seemed to be a trend where black-grass plant emergence is higher in situations where straw is removed from the stubble. The effect of cultivations is less clear. In 2003, results suggest that black-grass plant emergence is higher where there have been no cultivations whereas the opposite seems to have occurred in 2002, although the plant numbers are low. As the seeds were surface sown at 1250 and 2000 seeds/m^2 it was interesting to note that only approximately 10% of the seeds can be accounted for.

2.3 Discussion

Through controlled environment and glasshouse experiments temperature has a greater effect on the dormancy of black-grass seed than moisture, with hot treatments producing more non-dormant seed than cool. (Steadman *et al*., 2004) researching *Lolium rigidum* (annual rye-grass) found that maturation temperature also had a profound effect on other aspects of seed production, with warm temperature reducing the number and size of mature seeds produced. Moisture has a secondary effect with drier conditions reducing seed dormancy. It is possible that these effects of drought and high temperature have a common physiological basis. Both conditions, if imposed during seed development, reduce the water content of mature seeds. Premature drying has been found to reduce the period of seed dormancy in wheat, and this effect was correlated with a reduction in abscisic acid content of developing kernels (Sawhney & Naylor, 1982). Abscisic acid is a germination inhibitor in several species. (Benech Arnold, Fenner & Edwards, 1992) determined that water stress during seed development reduced dormancy of *Sorghum halepense* (Johnsongrass) seeds through modifications in the properties of the glumes that, apparently, result in an enhancement of their permeability to oxygen diffusion. Droughted caryopses had twice the rate of oxygen supply compared with controls. It is not known if this difference accounts for the observed differences in seed germinability, but suggests that control glumes might be acting as a barrier for the satisfaction of oxygen requirements of the caryopses enclosed within them (Benech Arnold et al., 1992). Stimulation following heat stress at more mature stages of seed development of *Hordeum vulgare* L. (barley) is related to a thinner seed coat, increased permeability as evidenced by faster imbibition rate, and decreased water soluble inhibitor content of the seed (Khan & Laude, 1969). Therefore, higher temperatures and drought combine the effects of a reduction in abscisic acid and increased permeability of the glumes to oxygen diffusion and the seed coat to water soluble inhibitors, all of which may encourage non-dormancy in the seed.

Studies in which single environmental factors have been examined, under controlled conditions, have shown that the effects on seed weight of maternal environmental conditions depend on the timing of the treatment (Roach & Wulff, 1987). The timing of temperature stress during plant and seed development is important with the critical period in black-grass during latter seed maturation, irrespective of temperature conditions during head emergence and flowering (anthesis). Low temperatures during seed ripening of *Lolium* sp. (rye-grass, cultivar Gulf) greatly increased seed dormancy, whereas exposure to high temperatures immediately after anthesis reduced dormancy (Wiesner & Grabe, 1972). The critical period of latter seed maturation in black-grass can be related to mid-June to mid-July in field conditions.

When this information was put into the context of field scale populations from the geographical samples collected across England, the dormancy of the seed related closely to the meteorological data collected from representative weather recording sites. The period studied most closely, was from 15 June to 12 July over the four years from 2001 to 2004, and showed a very close relationship to the dormancy of black-grass seed. Longer periods were looked at (spanning the whole of June and July, and shorter time periods within these months) but the correlations became less clear when either early June or late July were considered (data not shown).

From the interpretation of the weather conditions for each year the greatest individual weather parameter affecting the dormancy of black-grass seed is temperature. The years 2001, 2003 and 2005, which had hotter than average temperatures during this critical period also, resulted in greater non-dormancy in the seed produced. 2002 and 2004 were both cooler years than the 30-year average and had a lower percentage non-dormant seed. This data fits very well with the results from the soil moisture and air temperature experiment, which indicate that temperature is the leading parameter affecting seed dormancy.

The discovery that moisture had a secondary effect in the soil moisture and air temperature experiments, is not so clear cut in the natural populations. The volume of rain that falls during the critical seed maturation period is not so well related to seed dormancy as the number of days over which that rain fell. This is presumably because hot and apparently dry years, such as 2003 and 2005, can have a few stormy days where a great deal of rain may fall, skewing the rainfall volume data, whilst the rest of the period may be dry and hot. Looking at hours of sunshine and solar radiation in conjunction with rainfall can add information as to the likeliness that days were frequently overcast with light rainfall, or clear and sunny with intermittent heavy showers. In the latter case evapotranspiration would be enhanced and the overall effect would tend towards a hot and dry period. The cooler and more overcast years of 2002 and 2004 resulted in greater seed dormancy than the hotter and sunnier years of 2001, 2003 and 2005.

The dormancy of additional grass species (Italian rye-grass, barren brome and meadow brome) from the summer of 2004 to see if any comparison could be made with the knowledge that we have of black-grass seed dormancy. There were fewer samples than for black-grass, but the percentage non-dormancy was much more variable in each case when germinated within two weeks of collection. Two months after collection both the Italian rye-grass and barren brome samples had lost some of their dormancy and there was less variation within the samples. Italian rye-grass is a cultivated grass species and therefore derived from commercial cultivars bred to vary in dormancy. Barren brome and meadow brome are self pollinating which tends to lead to greater genetic diversity between discreet populations and may affect dormancy. It is notoriously difficult to determine when the seeds of brome species are ripe, so with different technicians collecting the seed from around the country there is increased potential for variation in seed ripeness. This in turn will lead to greater variability in the percentage dormancy of the samples.

The microplot trial tested dormancy determined in the lab, under field conditions. Of the black-grass populations sown, the clearest effects were shown by seeds derived from the cool wet (CW) and hot wet

(HW) treatments of the pot experiment. The greater seed dormancy of the CW treatment carried through to plant emergence in field conditions. The CW seeds were slower to emerge than the HW treated seeds, with approximately 6-8 weeks delay in plant emergence patterns. The HW treated seeds rapidly emerged after sowing. The delay in emergence due to dormancy status of black-grass seed was very slightly reduced by watering, as watered seeds of both the HW and CW treatments were more advanced than their un-watered replicates.

As only approximately a quarter of the seeds sown on the microplot trial was accounted for through emergence counts, the topsoil was removed from the plot and the remaining black-grass seeds extracted. This was done partly to test the efficiency of the seed extraction method. More seeds were recovered from the CW plots than the HW, but this was to be expected, as there had been fewer seeds accounted for through emergence counts. For both populations the percent recovery (including emerged seeds) was approximately 60 percent of the original seed sown, which was an excellent recovery when taking into account losses through predation and seed death. Of the recovered seed that had viable caryopses 96 and 97 percent germinated in the incubator for CW and HW treatments respectively. This indicates that the majority of the seeds remaining in the soil are still viable, irrespective of the treatment, and will stay dormant until conditions become favourable to them. For the HW treatment this amounts to approximately 10 percent of the original seed and for the CW treatment it is as much as 20 percent of the seed burden. Potentially this could have implications for spring-sown crops. Where dormancy is high there are likely to be more viable but un-germinated seed in the spring which could be stimulated to grow by spring cultivations. Field reports in 2005 suggest that there was a ‘good’ flush of black-grass in early spring sown crops and this may have been due to the black-grass seed set in 2004 having relatively high dormancy. Work undertaken by Peters (1982) looking at the effects of water stress on *Avena fatua* (wild oat) found that after 40 months in the soil, 8% of the viable seeds from unstressed plants remained as compared to none from those of stressed plants. This suggests that greater dormancy or improved seed quality (as illustrated by greater starch content) allowed longer survival by seed matured under unstressed conditions.

3 SHORT-TERM TRIALS

The objectives of the short-term trials were to quantify the relative importance of management and natural factors on black-grass seed arising from both freshly shed seed and the seedbank. The aims were to produce practical guidelines to reduce cultivation and herbicide costs by using improved knowledge of black-grass weed biology.

3.1 Materials and methods

3.1.1 Site details

The short-term experiment was located at four sites, with heavy soil types, in the east of the UK (Table 3-1).

Table 3-1. Short-term trials site location.

Site name	Harvest year	Location	Soil Type
Boxworth	2003-2005	Boxworth, Cambs	Clay
Rothamsted	2003, 2004	Woburn, Beds	Sandy loam
	2005	Rothamsted, Herts	Clay loam
TAG	2003-2005	Heveningham, Halesworth, Suffolk	Clay loam
Velcourt	2003-2005	Charlbury, Oxon	Sandy clay loam

The site at Velcourt in 2003 had no black-grass and has been excluded from the data. A field with a known high black-grass pressure was selected for the experiment but no black-grass germinated in the year of the project. The previous crop had been winter oats, which may have out-competed the black-grass so that it failed to emerge and set seed.

3.1.2 Treatments

In each year there were ten treatments and these are detailed in Table 3-2, the trials were sown to an autumn sown winter wheat. The previous crop was winter wheat with the straw chopped and spread. The primary cultivations were done as per treatment with target depths as below:

- Disc – 5-10 cm, tines at shallowest settings
- Plough - 25cm
- Direct drilling – as conditions allow

All treatments were treated with a non-selective herbicide prior to drilling, but where cultivations were done up to a week before harvest a non-selective herbicide was applied prior to this cultivation.

The primary cultivations were done as the method and at the timing as specified in the treatment list, further cultivations were done to best commercial practice to establish a seedbed. At drilling the seedrate used was appropriate to reach a spring population of 250 plants/m² from the early drilling date or 350 plants/m² from the later drilling. Plots did not receive an autumn pre-emergence herbicide; post-emergence herbicides were applied according to crop and weed growth stage. Dates of all cultivations and treatment dates are at Appendix 8-1. Broad-leaved weed, pest and disease sprays and spring applications of fertiliser were applied as an overall spray to the trial where necessary.

Table 3-2. Short-term trial treatments

Trt. No.	Primary cultivation method	Timing	Sowing date*
1.	Disc cultivate and consolidate to stale seedbed	As soon as possible after harvest	Late
2.	Disc cultivate and consolidate to stale seedbed	As soon as possible after harvest	Early
3.	Disc cultivate and consolidate to stale seedbed	Up to one week before or on same day as drilling	Late
4.	Disc cultivate and consolidate to stale seedbed	Up to one week before or on same day as drilling	Early
5.	Direct Drill	-	Late
6.	Direct Drill	-	Early
7.	Plough and press	As soon as possible after harvest	Late
8.	Plough and press	As soon as possible after harvest	Early
9.	Plough and press	Up to one week before or on same day as drilling	Late
10.	Plough and press	Up to one week before or on same day as drilling	Early

* The target for the early drilling date was before 15 September, and for late drilling after 15 September, A minimum of three weeks was the target between drilling dates.

Table 3-3. An explanation of codes used in data presentations

Code	Explanation	Code	Explanation
DC	Primary cultivation - Disc	A	Time of primary cultivation – immediately after harvest
P	Primary cultivation - Plough	B	Time of primary cultivation – up to one week before drilling
DD	Direct Drill	E	Target drilling date – early, before 15 September
		L	Target drilling date – late, after 15 September, or three weeks after early drilling

3.1.3 *Experimental design*

The experiment was done as a randomised block design. There were three replicates each year (four at Rothamsted in 2003). Plot size was a minimum of 4 m wide and 18 m long.

3.1.4 Assessments

Each year assessments were made in the previous crop to record the level of black-grass. Seed was collected at three timings (10, 50 and 90% seed shed) and sent to Rothamsted for assessment of dormancy level. Details of the method used are attached at Appendix 8-2.

Soil seed-bank sampling was done on two dates; Post-harvest on a per replicate basis at three depths (0-1 cm, 1-10 cm and 10-20 cm), post-winter at 0-10 cm done in treatments 1-6, 7 and 9. Details of the sampling method are at Appendix 8-3. Assessment dates are detailed at Appendix 8-4.

Grass weed counts were done at three timings; in the stubble immediately post-harvest, immediately prior to spraying off and drilling and immediately before the application of the post-emergence herbicide. All counts were in the absence of a pre-emergence herbicide. Assessment dates are detailed at Appendix 8-4.

Wheat plant counts were done at GS 13-14. Grass weed counts were done immediately after harvest in the stubble, prior to primary cultivation, prior to spraying off and drilling, prior to the post-emergence spray and at GS 30. Head counts of both wheat and black-grass were done in July. Assessment dates are detailed at Appendix 8-4.

3.1.5 Statistical analysis

Black-grass population data were logged to base 10 and subjected to analysis of variance in GENSTAT, data are presented back transformed. Error bars on figures are at 95% confidence level.

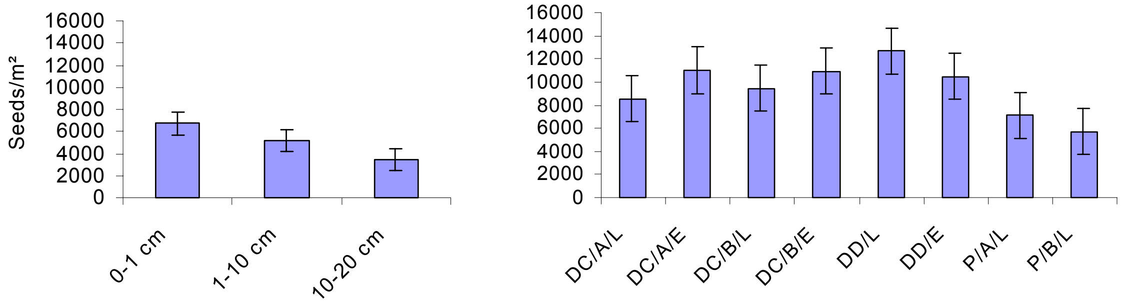
Seedbank data was subjected to analysis of variance in GENSTAT.

Wherever any direct comparisons were made between seed densities at 0-1, 1-10 and 10-20 cm depths, 'seed density m^{-2}' refers to a standardised soil volume of 0.05 m^3 (1 x 1 x 0.05 m). To achieve this, the seed numbers m^{-2} for the 0-20 cm soil cores were divided by three, to give an estimated number comparable to that quoted for the 0-1 cm depth. For both depths, therefore, the seed numbers quoted are those for a hypothetical 0.05 m^3 of soil.

3.2 Results and relevant data

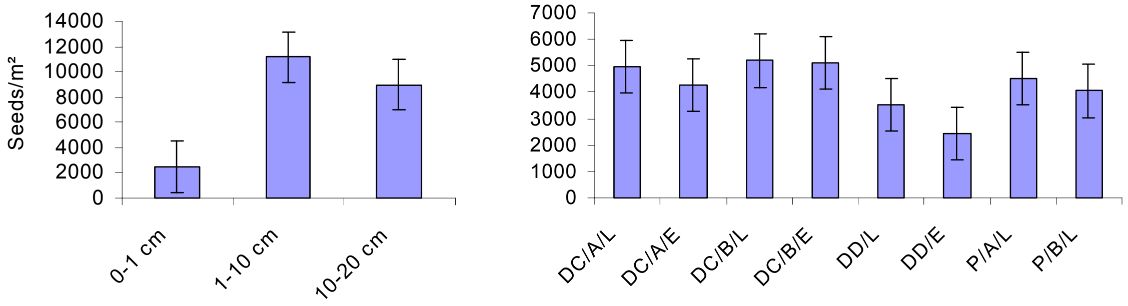
3.2.1 Seedbank samples

Generally black-grass seed numbers were lower at depth in the soil profile than at 0-1 cm as would be expected, the only exception was at Rothamsted in 2003 where less seeds were present on the surface than at depth. Black-grass numbers in the seedbank declined over the winter period and this ranged from 0-99%. The losses measured were variable and inconsistent with treatment. At the spring seedbank assessment seed numbers were lower in the ploughed treatments but these effects were not consistent for all sites (Figure 3-1, Figure 3-3, Figure 3-4 and Figure 3-5).



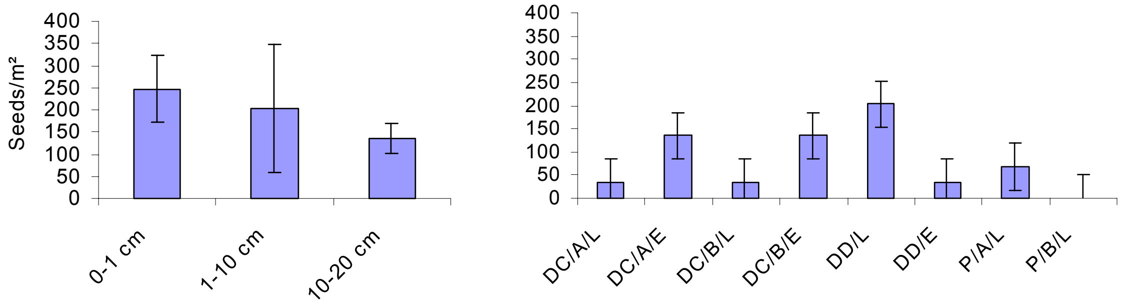
a) autumn (0-20 cm in three increments) b) spring (0-10 cm)

Figure 3-1. Black-grass seeds present in the Boxworth seedbank, harvest year 2003.



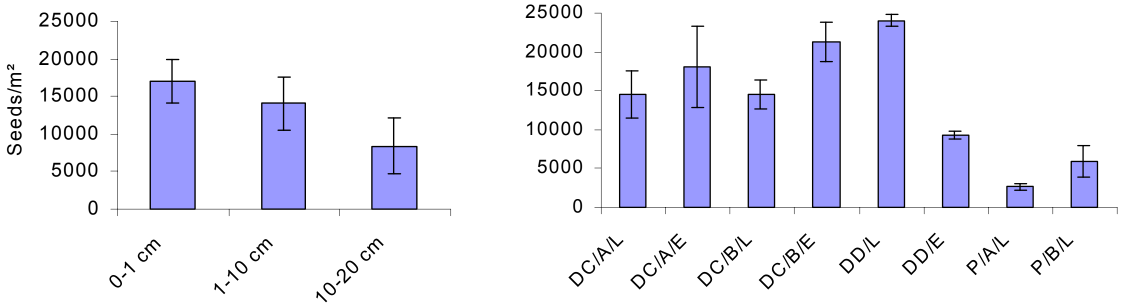
a) autumn (0-20 cm in three increments) b) spring (0-10 cm)

Figure 3-2. Black-grass seeds present in the Rothamsted seedbank, harvest year 2003.



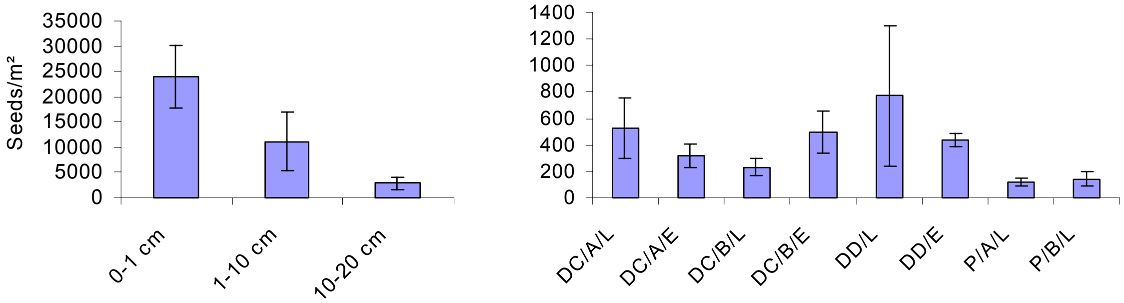
a) autumn (0-20 cm in three increments) b) spring (0-10 cm)

Figure 3-3. Black-grass seeds present in the Rothamsted seedbank, harvest year 2004.



a) autumn (0-20 cm in three increments) b) spring (0-10 cm)

Figure 3-4. Black-grass seeds present in the Rothamsted seedbank, harvest year 2005.



a) autumn (0-20 cm in three increments) b) spring (0-10 cm)

Figure 3-5. Black-grass seeds present in the Velcourt seedbank, harvest year 2004.

Black-grass seed numbers in the seedbank did not closely reflect the above ground population on a plants per unit area basis, but there was a tendency for sites with a high seedbank population to have higher above ground populations (Table 3-4).

Table 3-4. Relationship between black-grass in the seedbank and above ground populations.

Site and harvest year	Seedbank (seeds/m²) Autumn 0-20 cm	Seedbank (seeds/m²) Spring 0-10 cm	Plant counts (plants/m²) Stubble	Plant counts (plants/m²) Pre-sowing and drilling	Plant counts (plants/m²) Pre-post-emergence spray
Boxworth 2003	15374	9489	103	252	49
Rothamsted 2003	22641	4259	134	253	872
Rothamsted 2004	586	81	7	69	43
Rothamsted 2005	31105	13784	9	2225	2082
Velcourt 2004	37920	381	376	339	1300

3.2.2 *Dormancy levels*

Dormancy levels for the experiment are presented in Table 3-5. Sites were similar within years with Velcourt 2003, 2004 and Boxworth 2004 varying slightly from the overall annual mean.

Table 3-5. Dormancy levels of black-grass in the short-term experiments.

Sampling year (autumn)	Dormancy level (% germination) 2002	2003	2004
Site			
Boxworth	31	53	62
Rothamsted	26	58	24
TAG	26	53	18
Velcourt	30	70	42
Mean	28	59	37

3.2.3 *Rainfall*

Monthly rainfall is presented in Table 3-6. Autumn 2003 was the driest of the three years of the experiment at all sites. Autumn 2004 was slightly drier than 2002. Table 3-7 gives details of key dates in the experiments

Autumn 2002 was classified as a high dormancy with a rain delayed harvest. This resulted in a mid-late August harvest date. August and September were drier (<77.0 mm) at Rothamsted and TAG but wet (136.3 mm) at Boxworth due to thunderstorms. The number of raindays for all three sites was the similar. Early drilling was in late September at Rothamsted and Boxworth, being delayed by rain at Boxworth and machinery availability at Rothamsted. The late drilling at these two sites was in December and January due to high autumn rainfall. At TAG drilling dates were in September and October.

Conversely 2003 was a low dormancy year with an early harvest date at Boxworth, Rothamsted and TAG. Harvest was later at Velcourt (26 August). Rainfall in August and September was low (<43 mm) at all sites. Drilling dates were mid-September and mid-October except at Velcourt where the knock-on result of the late harvest resulted in drilling dates of 26 September and 30 October.

2004 can be classed as an 'in-between' year, two sites with high dormancy black-grass and two with low dormancy. August and September were very wet (>100 mm) over a similar number of raindays. As a result harvest was delayed until late August or early September at all sites. Rothamsted, TAG and Velcourt were able to drill in late September or early October, but Boxworth was unable to drill until 1 November. At all sites late drillings were done in late November or mid December.

Table 3-6. Monthly total rainfall for Boxworth, Rothamsted, TAG and Velcourt (mm).

Site/Year	August	September	October	November	December	Total
Boxworth						
2002	2	134	87	57	23	304
2003	4	26	32	26	39	127
2004	92	21	34	49	24	221
Rothamsted						
2002	40	19	110	120	110	399
2003	5	21	38	102	74	239
2004	113	24	126	74	40	378
TAG						
2002	46	31	96	94	94	361
2003	11	19	41	82	50	204
2004	132	41	63	47	33	317
Velcourt						
2003	24	19	34	91	98	266
2004	158	52	157	38	37	442

Table 3-7. Details of site, dormancy level, previous crop harvest date, drilling dates and rainfall.

Site and harvest year	% germination (non-dormant)	Previous crop harvest date	Drilling date		Rainfall (mm)		
			Early	Late	between harvest & early drilling	between harvest & late drilling	Total Aug-Sept
Harvest 2003							
Boxworth	31	15-Aug-02	30-Sep-02	7-Jan-03	135	330	136
Rothamsted	26	30-Aug-02	26-Sep-02	10-Dec-02	20	262	60
TAG	26	15-Aug-02	16-Sep-02	10-Oct-02	39	49	77
Harvest 2004							
Boxworth	53	04-Aug-03	16-Sep-03	14-Oct-03	9	32	29
Rothamsted	58	09-Aug-03	19-Sep-03	17-Oct-03	9	30	26
TAG	53	05-Aug-03	13-Sep-03	14-Oct-03	13	34	30
Velcourt	70	26-Aug-03	30-Sep-03	28-Oct-03	22	30	43
Harvest 2005							
Boxworth	62	02-Sep-04	1-Nov-04	15-Dec-04	56	105	114
Rothamsted	24	22-Aug-04	29-Sep-04	14-Dec-04	46	252	138
TAG	18	08-Sep-04	7-Oct-04	17-Nov-04	57	129	173
Velcourt	42	28-Aug-04	10-Oct-04	25-Nov-04	107	245	210

3.2.4 Black-grass populations in uncultivated stubble.

In this section figures 3-6 to 3-8 are presented to give an overall picture of the emergence of black-grass populations in uncultivated or direct drilled plots over time. Counts were done at three timings; in the stubble immediately post-harvest (mean of all plots); immediately prior to spraying off and drilling (uncultivated plots); Immediately before the application of the post-emergence herbicide (direct drilled plots). All counts were in the absence of a pre-emergence herbicide.

The sites have been grouped into categories: black-grass dormancy level, total rainfall during August and September and pre-post emergence spray application black-grass population (Table 3-8). At high dormancy sites black-grass had less than 50% of seeds with the capacity to germinate immediately (non-dormant), conversely low dormancy sites had black-grass with more than 50% of seeds that will germinate immediately (dormant). The results showed that black-grass population at the low dormancy sites was higher than at the high dormancy sites at the stubble count (one week after harvest) but lower at the later counts (nine to 16 weeks after harvest) (Figure 3-6).

The total rainfall received in August and September was selected as a method of grouping as it reflects the conditions for black-grass plant emergence after shedding, the level of black-grass seed dormancy and drilling date. Rainfall during August and September had little effect on black-grass populations immediately post-harvest in the stubble but numbers were greater where wetter pre-drilling. The dry conditions were reflected in higher black-grass numbers at the time of the post-emergence herbicide (Figure 3-7).

Sites were grouped for population to see if they responded similarly to treatment at the two population levels. There was a simple relationship between black-grass numbers and high population sites as expected (Figure 3-8).

Table 3-8. Details of site grouping for dormancy level, rainfall during August and September and black-grass population.

Dormancy level	Total rainfall in August and September	Black-grass population at the pre-post-emergence spray count	Dormancy level and total rainfall in August and September
Low (> 50%)	Wet (>100 mm)	High (>200 black-grass/m^2)	High (<42%), Wet (>100 mm
Boxworth 04	Boxworth 03	Rothamsted 03	Rothamsted 05
Rothamsted 04	Rothamsted 05	TAG 03	Boxworth 03
TAG 04	TAG 05	TAG 04	TAG 05
Velcourt 04	Boxworth 05	Velcourt 04	High (<42%), Dry (<100 mm)
Boxworth 05	Velcourt 05	Boxworth 05	Rothamsted 03
		Rothamsted 05	TAG 03
High (<42%)	Dry (<100 mm)		Low (> 50%), Wet (>100 mm)
Boxworth 03	Rothamsted 03	Low (<125 black-grass/m^2)	Boxworth 05
Rothamsted 03	TAG 03	Boxworth 03	Velcourt 05
TAG 03	Boxworth 04	Boxworth 04	Low (> 50%), Dry (<100 mm)
Rothamsted 05	Rothamsted 04	Rothamsted 04	Boxworth 04
TAG 05	TAG 04	TAG 05	Rothamsted 04
Velcourt 05	Velcourt 04	Velcourt 05	TAG 04
			Velcourt 04

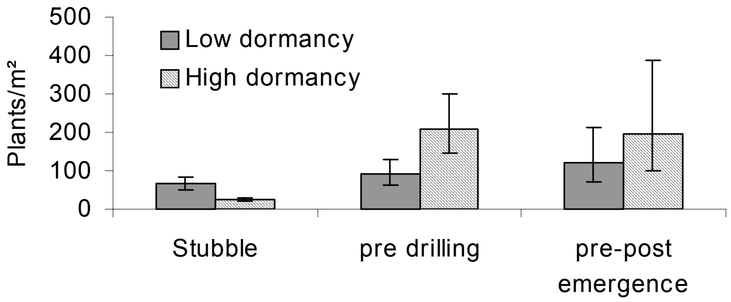


Figure 3-6. The effect of dormancy on black-grass populations at three count dates, mean of all sites and years (antilog).

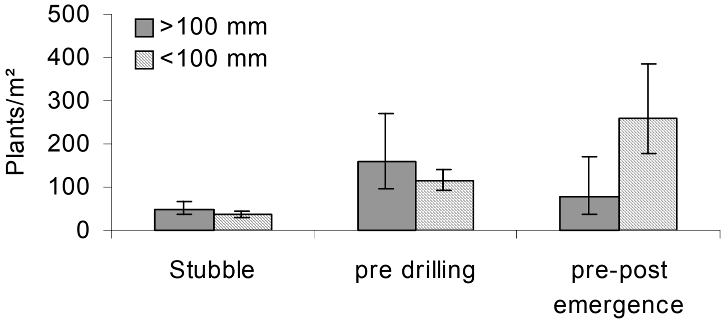


Figure 3-7. The effect of total rainfall in August and September on black-grass populations at three count dates, mean of all sites and years (antilog).

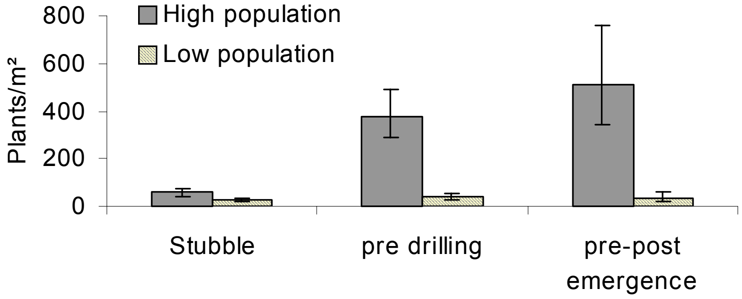


Figure 3-8. Black-grass populations at three count dates, mean of all sites and years, sites split for inherent population levels (antilog).

Throughout the next sections data are presented at each count date.

3.2.5 Post-harvest stubble counts

Counts of black-grass seedlings were done in the stubble just after harvest of the previous wheat crop. There were differences in counts between sites and years (Table 3-9). Counts were significantly ($P<0.001$) higher where dormancy was low (>42%) and slightly higher where rainfall during August and September was high (>100 mm), but this was not significant (Figure 3-9and Figure 3-10). Sites have been split into dormancy/rainfall groups (Table 3-8) to show the effects of rainfall in August and September on seeds of different dormancy levels. Counts were lower when dormancy was high even in high rainfall situations ($P<0.001$). (Figure 3-11).

Table 3-9. Black-grass populations in the stubble (antilog).

Site	Sampling year 2002	2003	2004
Boxworth	95	16	238
Rothamsted	118	6	6
TAG	41	14	2
Velcourt	0*	338	618
Mean	78	26	40

*There was no black-grass at this site and was not included in the mean.

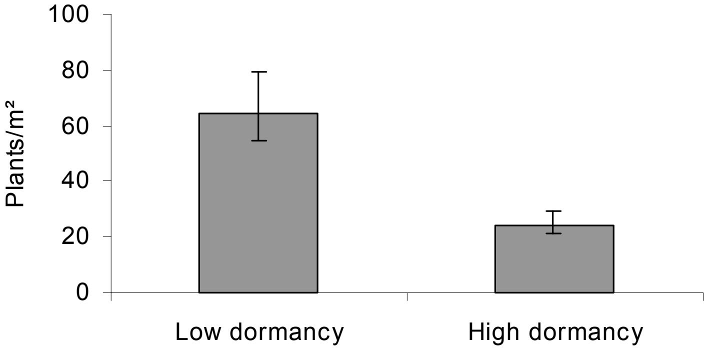


Figure 3-9. The relationship between dormancy level and black-grass counts in the stubble (antilog).

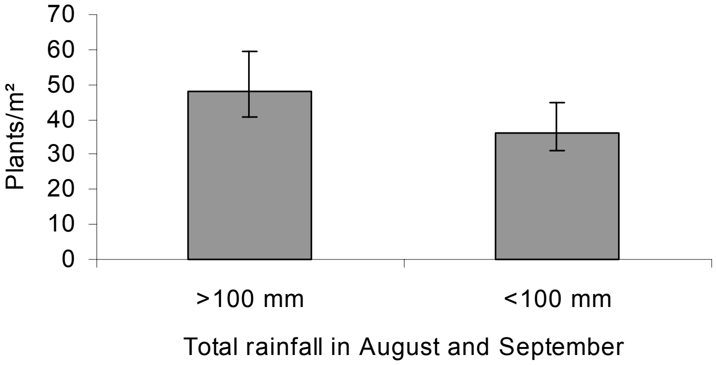


Figure 3-10. The relationship between total rainfall (mm) during August and September and black-grass counts in the stubble (antilog).

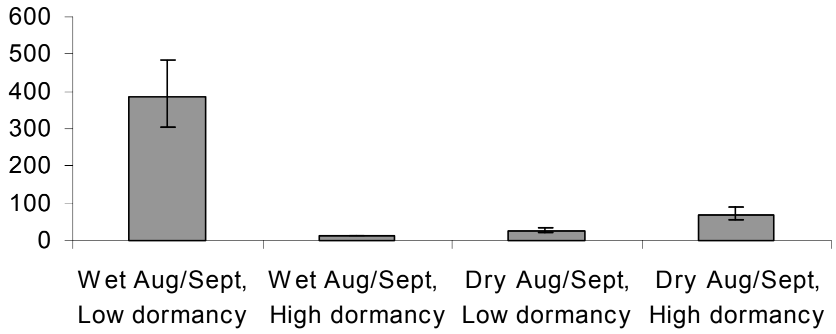


Figure 3-11. Effect of seed dormancy and total rainfall in August and September on black-grass counts in the stubble (antilog).

3.2.6 *Prior to spraying off and drilling*

These counts were done on plots prior to application of a non-selective herbicide and before drilling and reflect the black-grass that emerged after the early primary cultivation or in the uncultivated stubble. The timing of these counts was between three and 17 weeks after harvest. Prior to spraying off and drilling, more of black-grass was present where stubble had remained uncultivated and was lowest after ploughing (*P*<0.001, Figure 3-12).

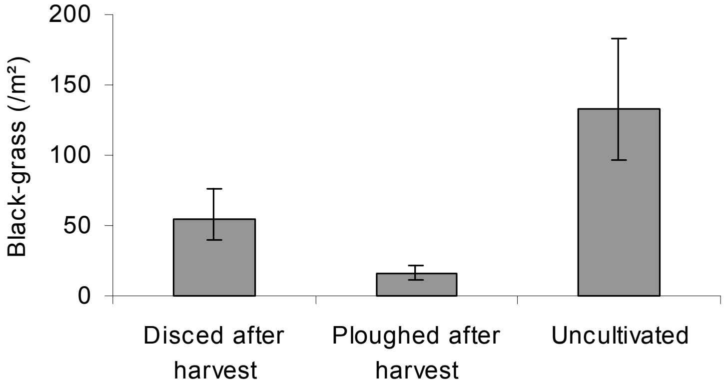


Figure 3-12. Black-grass populations prior to spraying off and drilling expressed (antilog).

Black-grass populations were lower in the low dormancy situation and greater were dormancy had been high (*P*<0.001). The ploughing result is interesting as the lower numbers probably reflect seed pulled up from the seedbank rather than the seed shed at harvest (Figure 3-13).

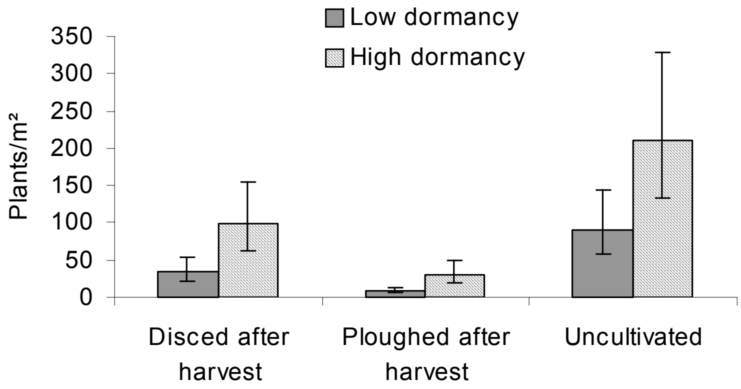


Figure 3-13. The effect of black-grass seed dormancy prior to spraying off and drilling (antilog).

Black-grass numbers were higher (*P*<0.001) where rainfall levels had been high during August and September (Figure 3-14)

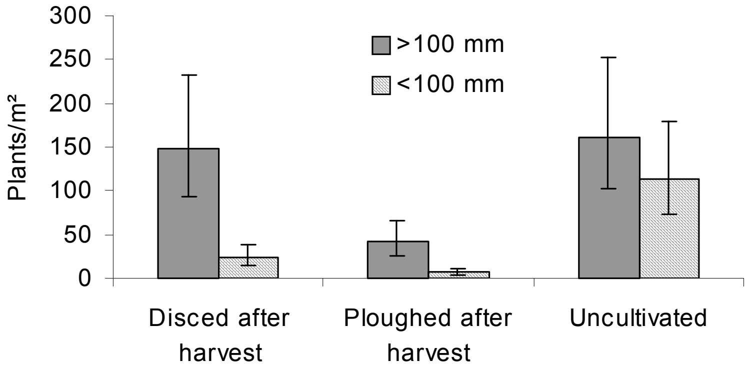


Figure 3-14. The effect of rainfall in August and September on black-grass populations prior to spraying off and drilling (antilog).

A combination of low dormancy black-grass seeds and a wet August and September resulted in the highest population after ploughing, discing or where stubble had been left uncultivated (*P*<0.001, Figure 3-15) Black-grass populations were higher in uncultivated stubble in dry years at both dormancy levels.

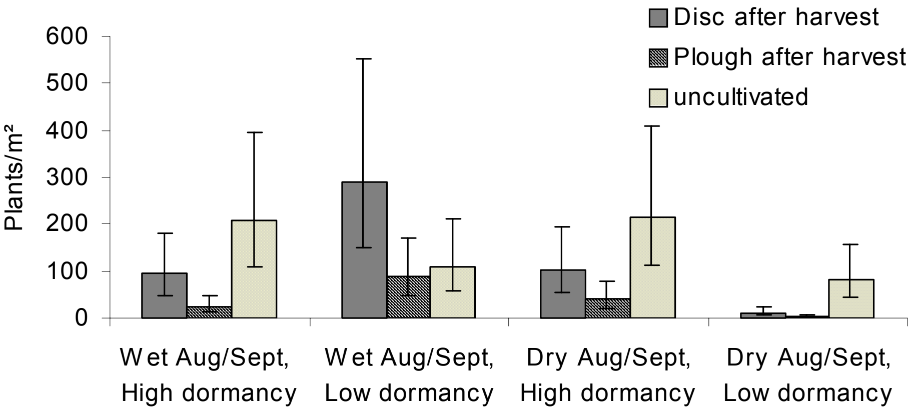


Figure 3-15. The effect of total rainfall during August and September and dormancy level on black-grass populations prior to spraying off and drilling (antilog).

3.2.7 *Pre-post-emergence spray counts*

The following data are taken from counts done prior to the application of the post-emergence spray. This count is a measure of the burden of black-grass to be faced by this critical spray. In this series of experiments no pre-emergence spray had been applied so that the true effects of cultivation, a non-selective herbicide spray and drilling date can be determined. Counts were done between 11 and 38 weeks after harvest.

In the following three figures, mean black-grass population in each of the ten treatments is presented as a percentage of the individual site mean and plotted against drilling date. As drilling date is delayed black-grass populations decrease (Figure 3-17).

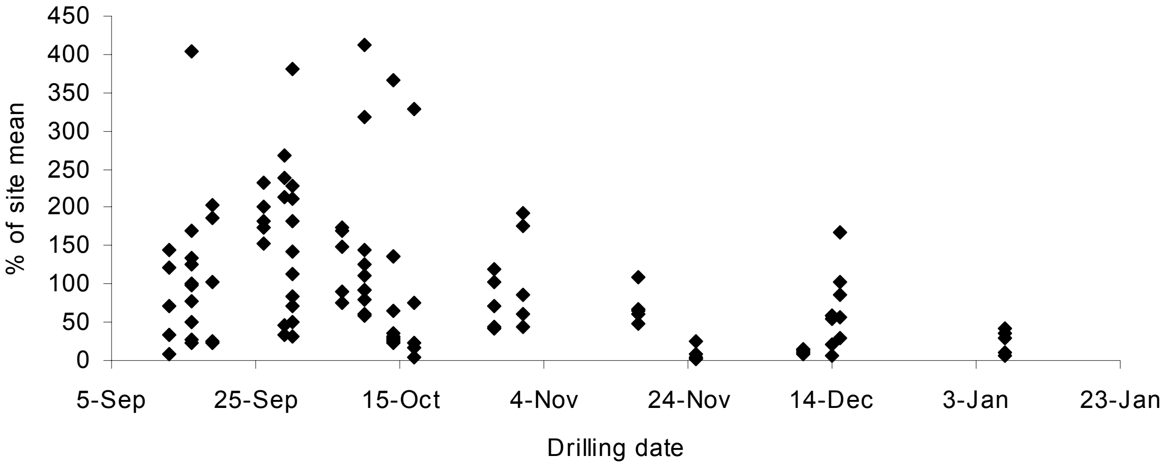


Figure 3-16. Relationship between pre-post-emergence spray black-grass counts and drilling date, expressed as a percentage of the site mean.

The sites were then split into dormancy groups as before (Table 3-8), there is no effect of dormancy on black-grass populations as drilling date is delayed (Figure 3-17). Figure 3-18 presents the same data grouped for cultivation method and no differences between these groups can be seen.

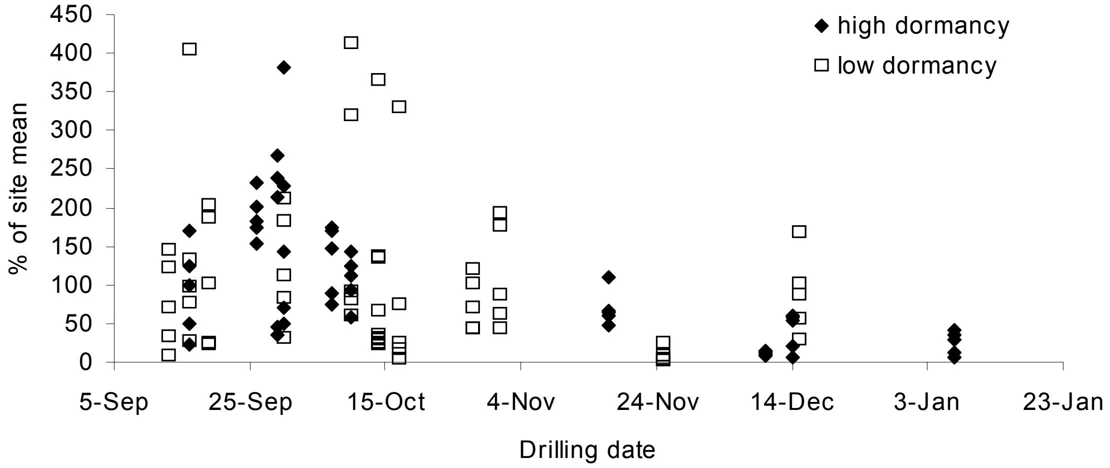


Figure 3-17. Relationship between pre-post-emergence spray black-grass counts, expressed as a percentage of the site mean and drilling date – effect of dormancy.

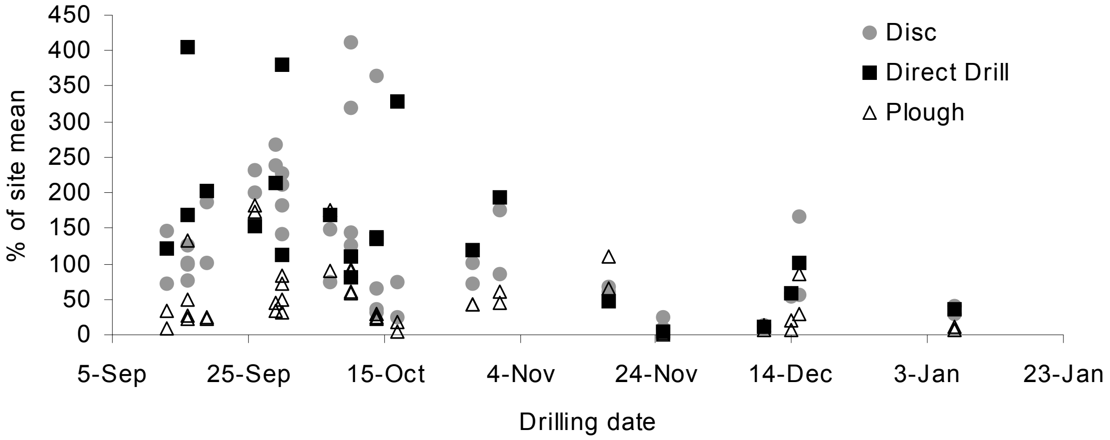


Figure 3-18. Relationship between pre-post-emergence spray black-grass counts, expressed as a percentage of the site mean and drilling date – effect of cultivation method.

Mean populations of black-grass before the application of the post-emergence spray, over the 11 sites, ranged from 14-2082 plants/m². When the sites were split into high and low dormancy groups, as before, black-grass population was approximately 50% greater at the high dormancy sites (*P*<0.01, Figure 3-19).

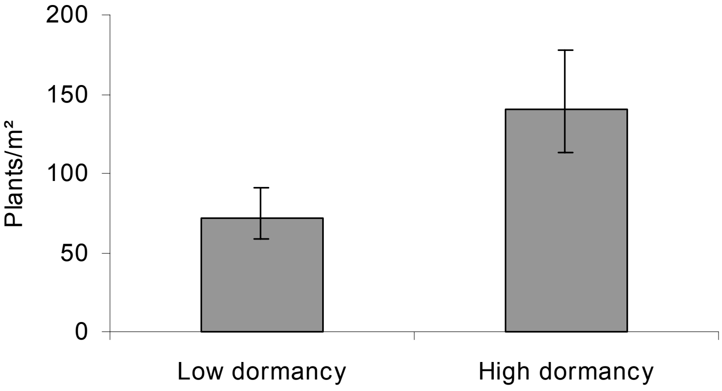


Figure 3-19. The effect of seed dormancy on black-grass populations (antilog).

3.2.7.1 Cultivations

Black-grass numbers following ploughing were significantly (*P*<0.001) lower than following disc cultivation and direct drilling (Figure 3-20). Ploughing, on average, gave black-grass populations 42% of discing. Black-grass populations after direct drilling were similar to those after discing.

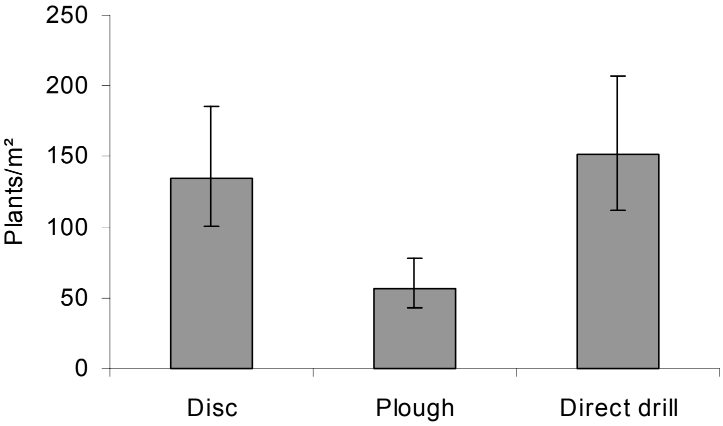


Figure 3-20. The effect of cultivation method on black-grass populations at the time of the post-emergence spray (antilog).

3.2.7.2 Cultivation and population

In Figure 3-21, data have been divided into two black-grass population groups; high (>200 plants/m²) and low (<125 plants/m²) as detailed previously. Populations were lowest in the ploughed situation at both populations (*P*<0.001). In the high and low populations ploughing resulted in 45% and 38% less black-grass than discing respectively. Therefore whilst ploughing was effective for overall control of black-grass, it had greater effect in high populations.

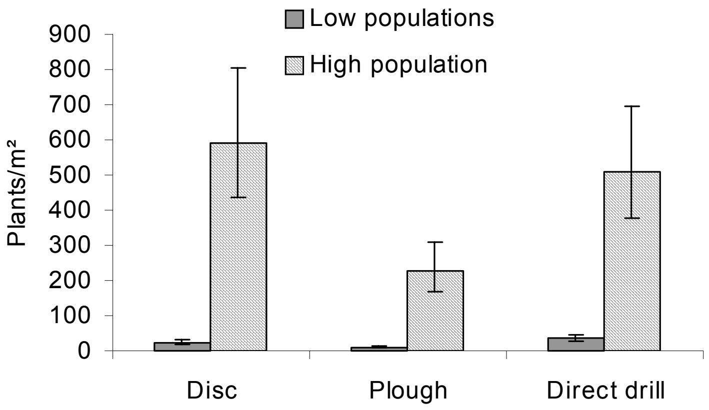


Figure 3-21. Black-grass populations at the time of the post-emergence spray – effect of cultivation in high (>200/m²) and low (<125/m²) black-grass populations (antilog).

3.2.7.3 Cultivation type and dormancy

In Figure 3-22, data have been divided into dormancy status as previously described; Low (>42% germination) and high (<50% germination). At the time of the post-emergence spray there was significantly more black-grass where dormancy was high, but both dormancy status groups responded similarly to different cultivation treatments.

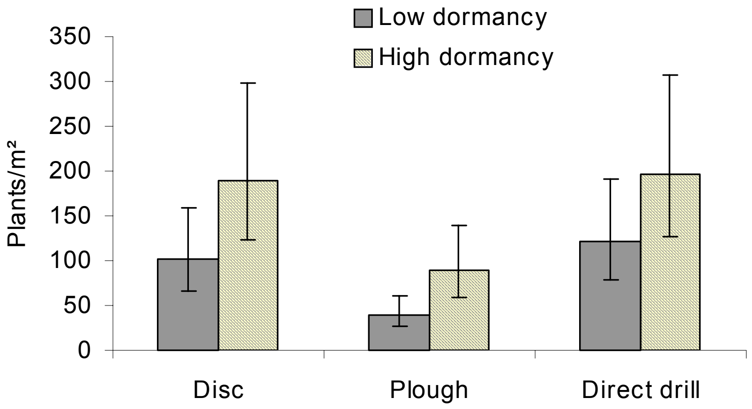


Figure 3-22. Black-grass populations at the time of the post-emergence spray – effect of dormancy level on cultivation choice (antilog).

3.2.7.4 Cultivation timing

The short-term experiments investigated two primary cultivation timings within the treatments, where cultivations were done immediately after harvest or within one week of drilling. In the next series of figures data are presented as timing of primary cultivation, then grouped as previously for dormancy level (Table 3-8) and a new grouping as drilling date (Table 3-10).

Table 3-10. Details of site grouping for drilling date and dormancy level.

Drilling date	Dormancy level and drilling date
Early (before 20 October)	High (<42%), Early (before 20 October)
Boxworth 03	Boxworth 03
Rothamsted 03	Rothamsted 03
TAG 03 (both drilling dates)	TAG 03 (both drilling dates)
Boxworth 04 (both drilling dates)	Rothamsted 05
Rothamsted 04 (both drilling dates)	TAG 05
TAG 04 (both drilling dates)	High (<42%), Late (after 20 October)
Velcourt 04	Boxworth 03
Rothamsted 05	Rothamsted 03
TAG 05	Rothamsted 05
Velcourt 05	TAG 05
	Low (>50%), Early (before 20 October)
Late (after 20 October)	Boxworth 04 (both drilling dates)
Boxworth 03	Rothamsted 04 (both drilling dates)
Rothamsted 03	TAG 04 (both drilling dates)
Velcourt 04	Velcourt 04
Boxworth 05 (both drilling dates)	Velcourt 05
Rothamsted 05	Low (>50%), Late (after 20 October)
TAG 05	Velcourt 04
Velcourt 05	Boxworth 05 (both drilling dates)
	Velcourt 05

NB. There are two drilling dates at each site.

Discing after harvest resulted in 26% less black-grass than discing before drilling (Figure 3-23). Ploughing after harvest resulted in 25% less black-grass than the later timing. There was significantly ($p<0.01$) less black-grass after ploughing but no significant differences between discing or direct drilling.

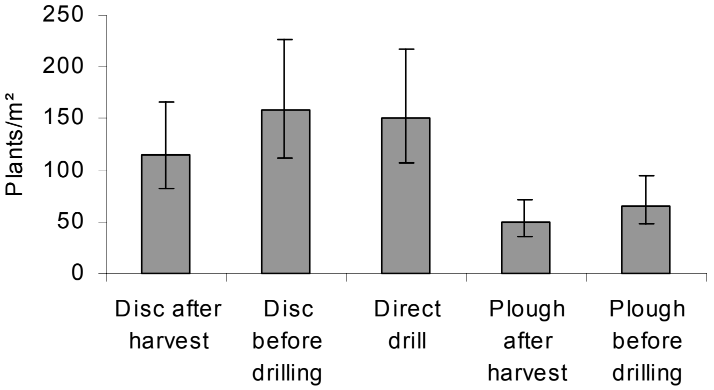


Figure 3-23. Black-grass populations at the time of the post-emergence spray – effect timing of the primary cultivation (antilog).

Figure 3-23 above gives a simplistic overview of the cultivation effect. Several factors have had greater effects and the following sections investigate this further.

3.2.7.5 Cultivation timing and drilling date

In Figure 3-24 the sites have been split into drilling date groups to represent early and late drilling, as previously detailed. The mean of all treatments showed that there was less black-grass where drilling had been delayed until after 20 October (*P*<0.05). All cultivation treatments responded similarly at the different drilling dates.

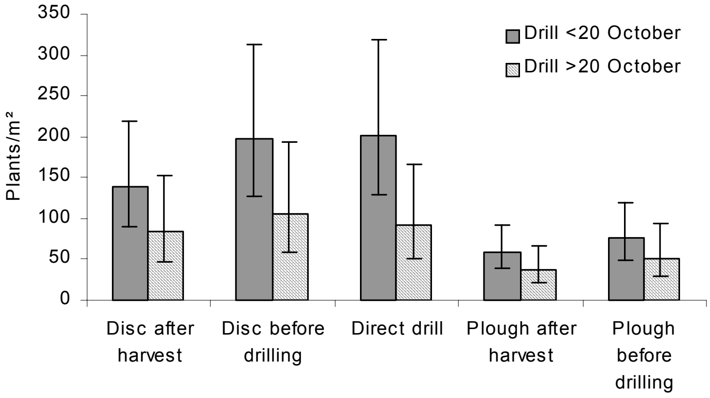


Figure 3-24. Black-grass populations at the time of the post-emergence spray – effect timing of the primary cultivation (antilog).

3.2.7.6 Cultivation timing and dormancy

The first hypothesis we tested in our analysis was ‘stubble cultivations immediately after harvest only reduce black-grass numbers in the subsequent cereal when dormancy is low’.

In Figure 3-25, the sites have been grouped for low and high dormancy as before in Section 3.2.7.3. In a low dormancy situation there was 45% less black-grass when discing was done immediately after harvest compared to the later timing (*P*<0.05), although this was not statistically significant. There was no advantage from discing early in high dormancy situations.

With ploughing there was an overall advantage from cultivation early (25% less black-grass), and both dormancy groups responded similarly. This data only partially supports this hypothesis; that only when dormancy was low did shallow stubble cultivations immediately after harvest help reduce black-grass numbers in the subsequent cereal crop. When the data for figure 3-25 is divided into the two drilling dates (Figure 3-26 and Figure 3-27) the hypothesis is proved correct.

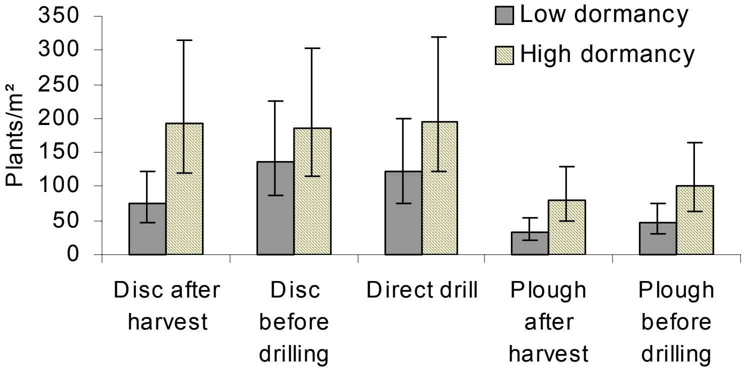


Figure 3-25. Black-grass populations at the time of the post-emergence spray – effect of dormancy on the timing of the primary cultivation (antilog).

3.2.7.7 Cultivation type, drilling date and dormancy

The second hypothesis examined was that: 'delayed drilling more successfully reduces black-grass in the crop where dormancy is low'.

In Figure 3-26 and Figure 3-27, the sites have been grouped by drilling date (before and after 20 October) and dormancy level (Table 3-10).

In low dormancy situations, discing before drilling resulted in 45% less black-grass than discing immediately after harvest ($P<0.05$, Figure 3-26). There was no difference in black-grass populations between the drilling dates. Black-grass populations at both drilling dates responded similarly to cultivation type/cultivation timing. However, in relation to our hypothesis we did show that when dormancy was low, discing immediately after harvest and delayed drilling reduced black-grass more than late cultivation or direct drill. However, ploughing was even more effective in reducing black-grass populations.

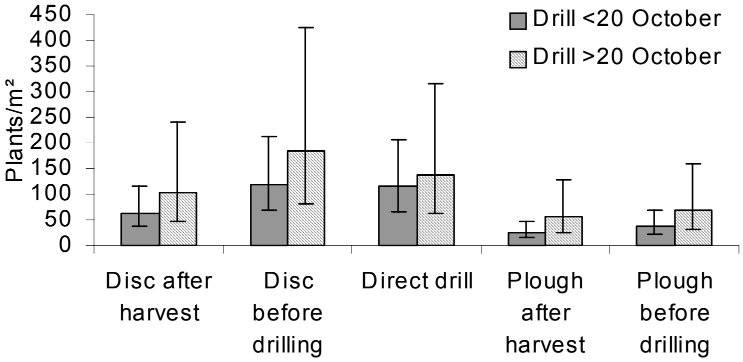


Figure 3-26. Low dormancy: black-grass populations at the time of the post-emergence spray –and drilling effects (antilog).

In a high dormancy situation, there was a significant advantage from delaying drilling (*P*<0.001). There were no differences in black-grass populations between the cultivation type/cultivation timing. Black-grass populations at both drilling dates responded similarly to cultivation type/cultivation timing. Ploughing immediately after harvest combined with late drilling resulted in 94% less black-grass than after direct drilling early (Figure 3-27).

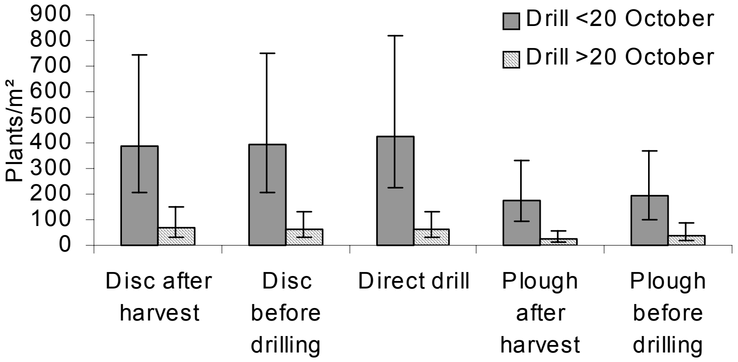


Figure 3-27. High dormancy: black-grass populations at the time of the post-emergence spray – drilling and cultivation effects (antilog).

3.2.8 Black-grass counts at growth stage 30 of winter wheat

At GS 30 black-grass populations were lowest after ploughing (*P*< 0.001, Figure 3-28), there were no differences between discing and direct drilling. Populations were highest in a high dormancy situation (*P*<0.001).

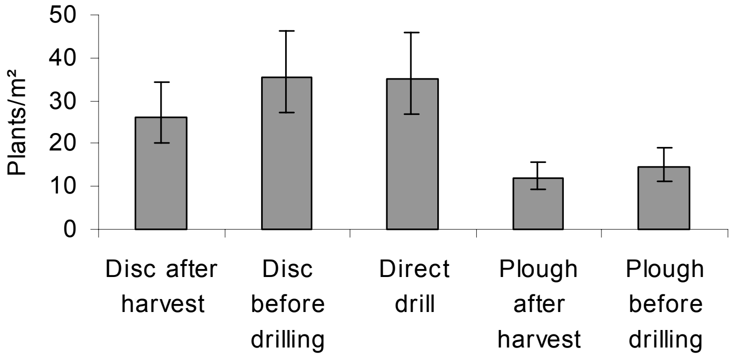


Figure 3-28. Effect of cultivation type and timing black-grass populations at GS 30 (antilog).

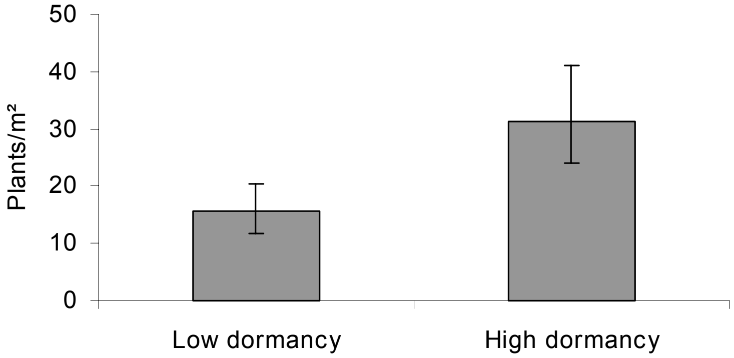


Figure 3-29. Effect of drilling date on black-grass populations at GS 30 (antilog).

3.2.9 Black-grass head count (GS 59)

At this growth stage the effects of dormancy and rainfall in August and September had disappeared. The only recordable effect was from delaying drilling date, especially when the primary cultivation was discing or direct drill (Figure 3-30). Numbers of black-grass heads were higher where drilling was before 20 October and significantly higher ($P<0.05$) where non-inversion tillage was used.

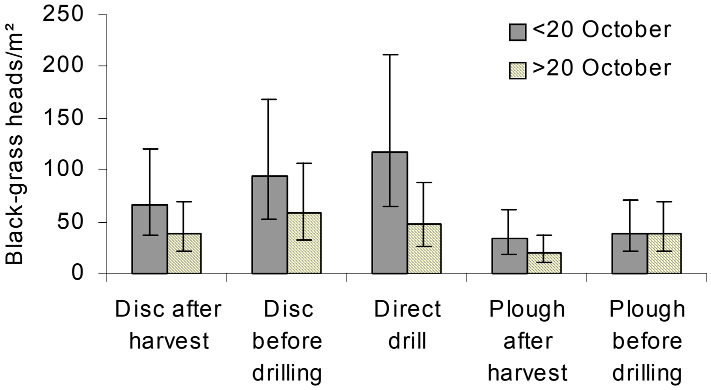


Figure 3-30. Effect of cultivation type, timing and drilling date on black-grass heads (antilog).

3.2.10 *Wheat population counts*

Wheat populations at GS 13-14 were greater (*P*<0.001) in all early drilled situations and where the primary cultivation had been ploughing (*P*<0.001, Figure 3-31).

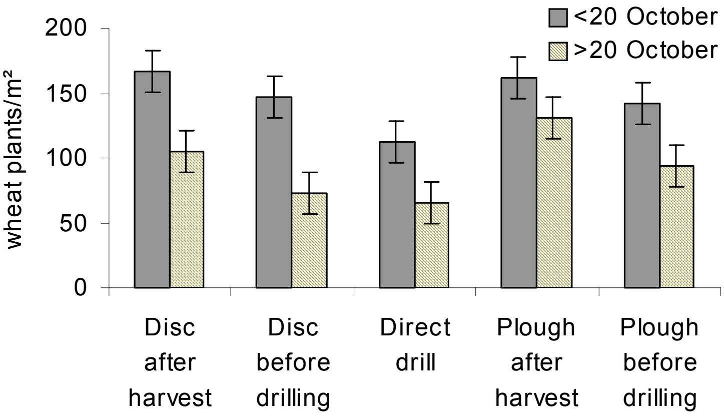


Figure 3-31. Effect of cultivation type, timing and drilling date on winter wheat populations at GS 13-14.

There was a significant effect of drilling date at GS 30 on winter wheat head number (*P*<0.05), and there was no [significant] effect of cultivation (Figure 3-32).

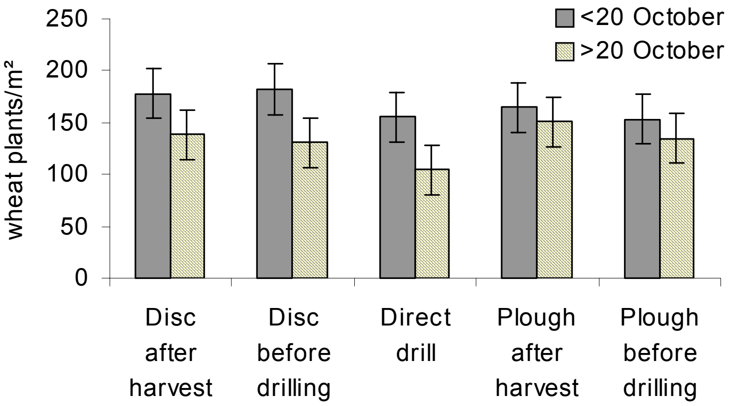


Figure 3-32. Effect of cultivation type, timing and drilling date on winter wheat populations at GS 30.

There was a significant effect of cultivation type/ timing on winter wheat ear number (*P*<0.01), but no effect of drilling date (Figure 3-34).

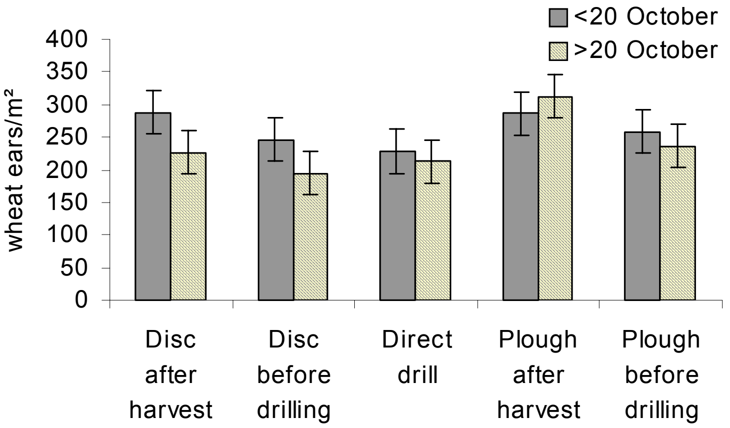


Figure 3-33. Effect of cultivation type, timing and drilling date on winter wheat ear number.

3.3 Discussion

The short-term trial series has resulted in a wide range of environmental conditions with which to test management strategies for black-grass of different seed dormancy. A range of primary cultivation methods; plough, disc (non-inversion) and direct drilling combined with two timings of primary cultivation; immediately after harvest and up to a week before drilling and two drilling dates; early and late were investigated. Assessments were done on the seedbank, black-grass and wheat populations but the experiments were not taken to yield.

The seedbank data has proved to be very variable. The sampling regime used was a proven technique but too coarse to find very small differences between treatments over a relatively short period in time. The data indicated that there was a large loss of viable black-grass seeds over the winter period but high populations of black-grass seed survive into the spring. The long-term experiment (Section 4) looks at the long-term changes in the seedbank. High seedbank populations were always associated with higher in-crop populations of black-grass.

Dormancy was an important factor influencing black-grass populations in the stubble immediately after harvest. When dormancy was low, in a wet autumn (2001) plant emergence was rapid, and black-grass plants could be seen in the crop prior to harvest. In a very dry year, but with low dormancy, (autumn 2003) plant emergence was delayed until significant rainfall occurred; this was also seen at both sites of the long-term trial. The most important question is when does dormancy break and black-grass free to germinate? The microplot trials at Rothamsted showed that seeds from a known more-dormant population were slower to germinate than the less-dormant seeds with a 6-8 week delay even in the presence of adequate water. Results from the short-term trials do indicate that dormancy has broken to some extent by the time of drilling as this count falls 6-11 weeks after harvest. Observations from spring 2005 indicated that there was a spring-flush of black-grass. The experiments have shown that all black-grass has some level of dormancy and germination of freshly shed seed can occur from before harvest through to a spring-flush. Figure 3-34 shows the time delays between harvest and cultivation, and harvest and drilling date that were experienced at 12 sites over a three-year period. These time delays probably reflect the typical situation on most UK farms, we need to know what factors cause black-grass dormancy to break so cultivations, and herbicides can be timed for maximum benefit.

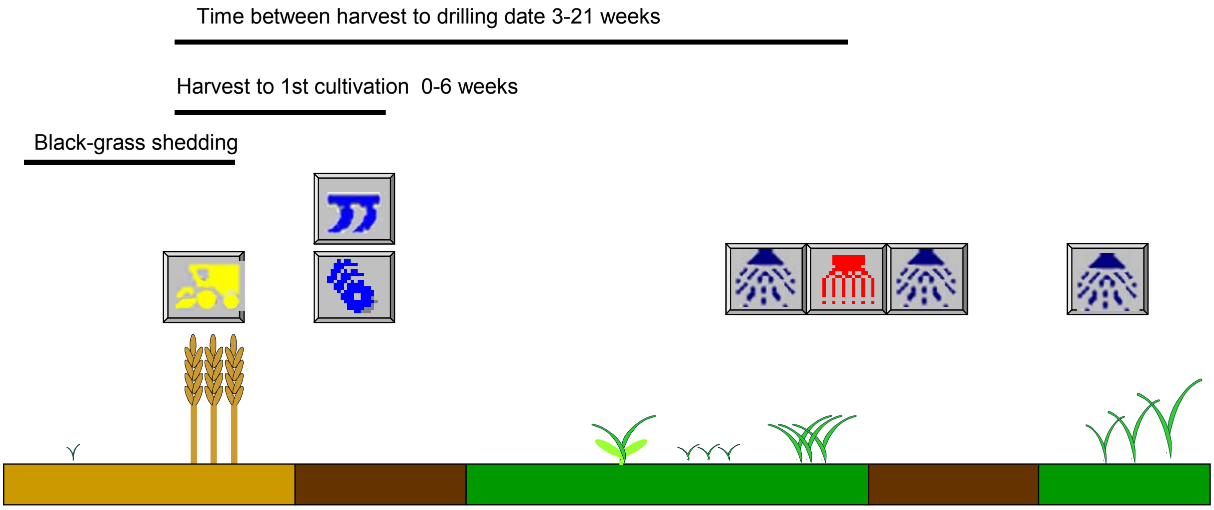


Figure 3-34. When does black-grass dormancy break?

Black-grass will germinate on the soil surface without the need for cultivation (Moss, 1979). The results showed that cultivations decreased the amount of black-grass that emerges before drilling. The most interesting effects of treatment can be seen with the counts done at the time of the post-emergence herbicide. This count reflects the burden that the post-emergence herbicides have to face; this series of experiments gives them a greater challenge as no pre-emergence herbicide was used. Overall, plough was the best primary cultivation for reducing black-grass populations to 34% of that after discing. In high-pressure black-grass situations this advantage was even greater (66%), Moss (1979) recorded 97% less black-grass between the two cultivations but the population after ploughing is dependant on seed brought up from the seedbank that subsequently germinates.

Timing of primary cultivation was an important factor; the short-term experiments looked at cultivations done immediately after harvest and up to one week before drilling. Overall, discing immediately after harvest resulted in 17% less black-grass than the later timing, for ploughing this figure was 24% but the dormancy of the stocks seemed to have a large impact on these reductions. Cultivating early was only beneficial in low dormancy situations, allowing time to control black-grass with before drilling cultivations and non-selective herbicide. Consolidation of any cultivation is necessary to retain moisture.

Delaying drilling date resulted in significantly lower black-grass populations in high dormancy situations only. When dormancy is high and there is a need to drill early, ploughing resulted in the best reduction of black-grass populations but this was not significant.

In low dormancy situations, a large proportion of black-grass will germinate before drilling as long as adequate moisture is available. For any given cultivation regime there were no significant differences between early and late drilling dates, however, if drilling early, ploughing did result in significantly lower black-grass populations than discing immediately drilling or direct drilling.

4 LONG-TERM TRIALS

4.1 Materials and methods

4.1.1 Site details

The long-term sites were located at two sites with heavy soil types in the east of the UK (Table 4-1).

Table 4-1. Location of sites for the long-term trial.

Site name	Location	Soil type
Boxworth	Boxworth, Cambs	Clay
Velcourt	Haverholme, Lincs.	Clay loam

4.1.2 Treatments

The plots were set up in autumn 2001 following a crop of winter wheat with the straw being chopped and spread. The plots were permanently located and treatments applied annually beginning in 2001 and ending in 2005. There were three treatments and these are listed in Table 4-2.

Table 4-2. Treatments in the long-term experiment.

Trt. No.	Description
1.	Annual plough
2.	Managed approach
3.	Annual minimum cultivation

Each year the crop was autumn sown winter wheat. The straw of the previous crop was chopped and spread. Primary cultivations were done as per treatment with target depths as below;

a) Disc – 5-10 cm, tines at shallowest settings

b) Plough 25cm

The managed approach, in 2001 and 2002 used a primary cultivation deemed suitable by the farm manager in consultation with a local adviser if appropriate. From autumn 2003, the site managers had results from the dormancy test (see section 4.1.4); the information was used to plan the cultivations used in the managed approach. The farm manager also made a decision on the cultivation programme for the managed treatment based on his current knowledge and this was recorded.

After primary cultivations were done, best commercial practice was used to establish a seedbed (Appendix 8-6). All treatments were treated with a non-selective herbicide prior to drilling. The seedrate used was appropriate to reach a spring population of 250 plants/m^2 from a September drilling or 350 plants/m^2 from an October drilling. Plots received an autumn pre-emergence herbicide and post-emergence herbicides were applied according to crop and weed growth stage. Spring applications of fertiliser, weed, pest and disease treatments were applied as overall treatments as appropriate.

4.1.3 Experimental design

The experiment was done as a randomised block design with three replicates. Plot size was 12 m x 24 m.

4.1.4 Assessments

A central core area was identified in the plot but not permanently marked out, all assessments were done in this central core area (Figure 4-1) in order to avoid any edge effects/cultivation, drill overlaps or atypical areas due to differential straw spread.

To assess the effects of the pre-emergence spray, two 2 m x 2 m herbicide shields were placed between the core area and the ends of the plot as shown in Figure 4-1. Pegs marked the position of the shields and the shields were removed after the spray had been applied.

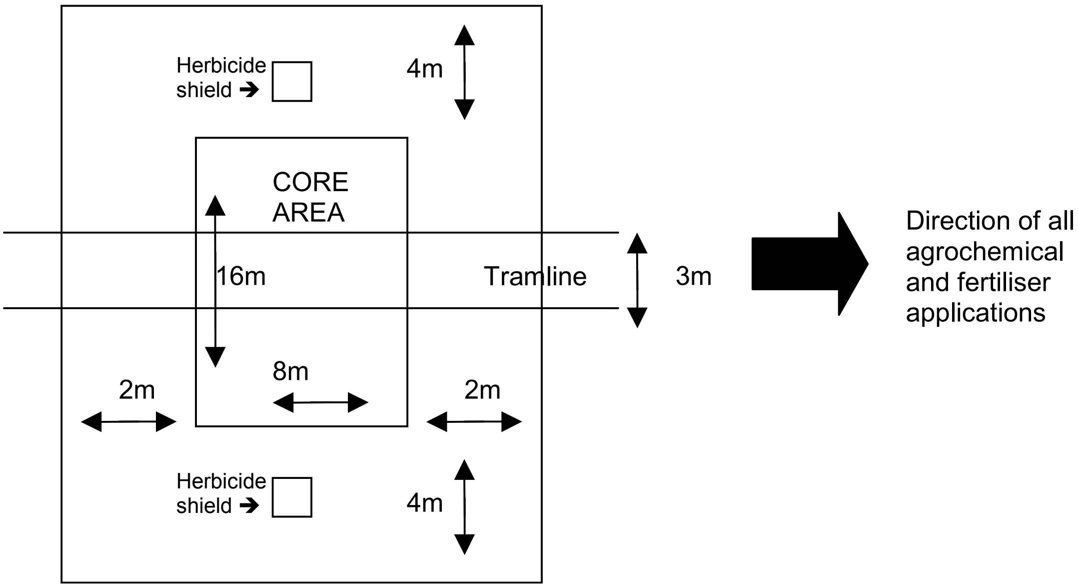


Figure 4-1. Individual plot layout in the Long-term trial.

Each year assessments were made in the previous crop to record the level of black-grass. Seed was collected at 50% seed shed and sent to Rothamsted for assessment of dormancy level. Details of the method used are attached at Appendix 8-2.

Soil seed-bank sampling was done on two dates; post-harvest on all plots at three depths (0-1 cm, 1-10 cm and 10-20 cm) and post winter (0-10 cm and 10-20 cm). Details of the method used are at Appendix 8-3. Assessment dates are detailed at Appendix 8-7.

Wheat plant counts were done at GS 13-14. Grass weed counts were done immediately after harvest in the stubble, prior to primary cultivation, prior to spraying off and drilling, prior to the post-emergence spray (in both the shielded and non-shielded areas) and at GS 30. Head counts of both wheat and black-grass were done in July. Assessment dates are detailed at Appendix 8-7. The trial was taken to yield in 2002-2004, but not in 2005 (after the project end)

4.1.5 *Statistical analysis*

Data were subjected to analysis of variance in GENSTAT.

4.2 Results and relevant data

A complete set of trial data is presented at Appendix 8-8.

4.2.1 *Primary cultivations*

In the managed approach in 2001-02, the farm manager selected the primary cultivation used. In the three following seasons dormancy data was used to aid selection of the primary cultivations (Table 4-3).

Table 4-3. Primary cultivations used in the managed approach treatment.

	Harvest year			
Site	2002	2003	2004	2005
Boxworth	Disc	Disc	Disc	Plough
Velcourt	Plough	Disc	Scratch-till	Plough

4.2.2 *Seedbank*

Seedbank sampling was done in the autumn and spring of each year. At Boxworth, by chance, the annual minimum cultivation treatment started with the lowest seedbank population. At this site there were no differences between the treatments (Figure 4-2).

At Velcourt the seedbank had large variations in black-grass seed numbers. Overall there were greater numbers of black-grass seeds in the annual minimum cultivation than the other treatments. In spring 2004 there were significantly less ($P<0.05$) in the annual plough treatment. Numbers remained high where minimum cultivations had been used (Figure 4-3).

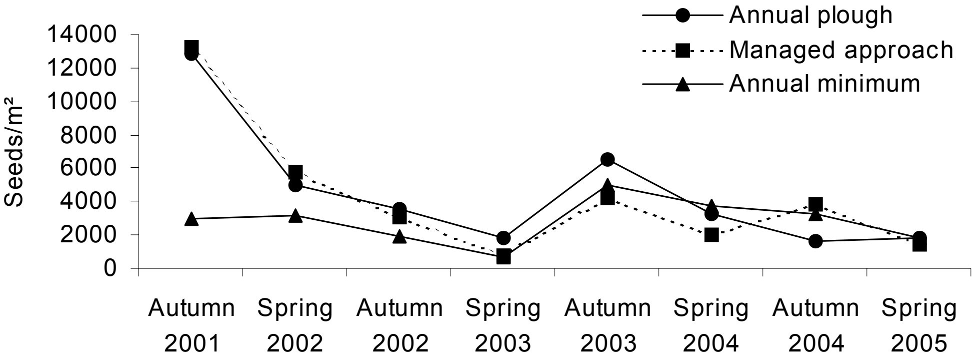


Figure 4-2. Total seeds in the seedbank at Boxworth – 0-20 cm (seeds/m²).

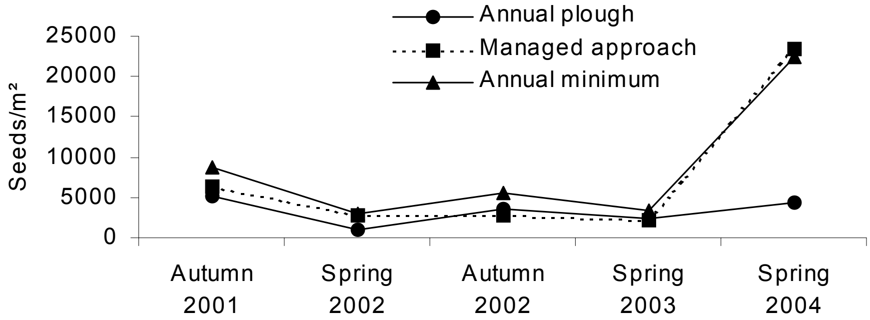


Figure 4-3. Total seeds in the seedbank at Velcourt – 0-20 cm (seeds/m²).

4.2.3 Dormancy levels

Dormancy levels for the experiment are presented in Table 4-4. Sites were similar within years except in 2001 and 2003. Dormancy levels on the two sites reflected the national pattern each year.

Table 4-4. Dormancy levels at the long-term sites.

	Dormancy level (% germination)			
Sampling Year	2001	2002	2003	2004
Site				
Boxworth	40	38	47	24
Velcourt	80	41	81	26

4.2.4 Grass weeds

At Boxworth, throughout the experiment black-grass numbers were lowest in the plough treatment. There was little difference between the managed and minimum cultivation treatments. In 2001 the site was cultivated using the Simba Solo to a depth of 10 cm as previous black-grass populations had been low. During the season, black-grass was well controlled by herbicides. In autumn 2002 the decision was taken to use the Simba Solo again on the managed plots although dormancy was high, but black-grass populations were low. Another successful year kept the black-grass levels under control. In autumn 2003 dormancy was low and it was predicted that the black-grass would germinate readily. The autumn was very dry but in the managed treatment drilling was delayed to maximise the emergence of black-grass before drilling. Black-grass populations were reduced by about 30% over the minimum cultivation and earlier drilling. Autumn 2004 was typified by high dormancy black-grass and the decision was taken to plough due to high black-grass populations (Figure 4-4).

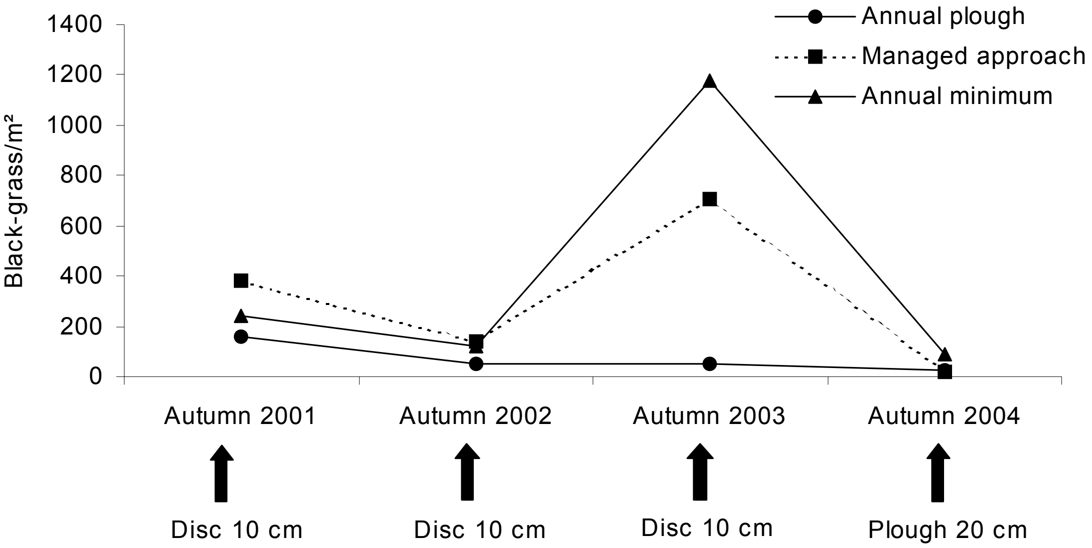


Figure 4-4. Boxworth - Black-grass populations before application of the post emergence spray, from autumn 2001 to autumn 2005 (arrows refer to treatment applied to managed plots).

At Velcourt, ploughing was used in the managed approach in autumn 2001 due to high black-grass populations in the previous wheat crop. Black-grass levels were kept to below 100 plants/m² (Figure 4-5). In autumn 2002, the Simba Solo, working at a depth of 15 cm, was used to keep black-grass seed on the surface. In autumn 2003, dormancy was very low and a ‘scratch’ tillage (tines to 5-7 cm) was used; unfortunately the dry season did not allow black-grass to germinate before drilling and populations of up to 1700 black-grass/m² were seen, levels of the weed were also high in the plough treatment. In order to control these populations and in a high dormancy year, ploughing was used in the managed treatment in autumn 2004. This brought the black-grass population down to a manageable level.

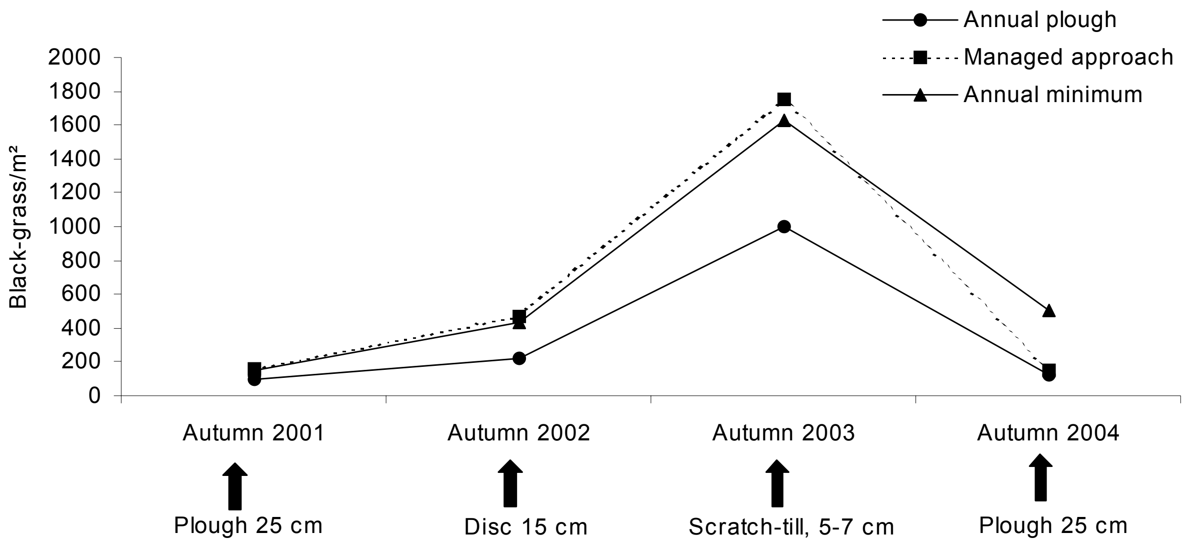


Figure 4-5. Velcourt - Black-grass populations before application of the post emergence spray, from autumn 2001 to autumn 2005 (arrows refer to treatment applied to managed plots).

4.2.5 *Wheat population*

There were no differences between sites and years, therefore winter wheat populations were averaged across treatments. There were no differences between treatments (Figure 4-6).

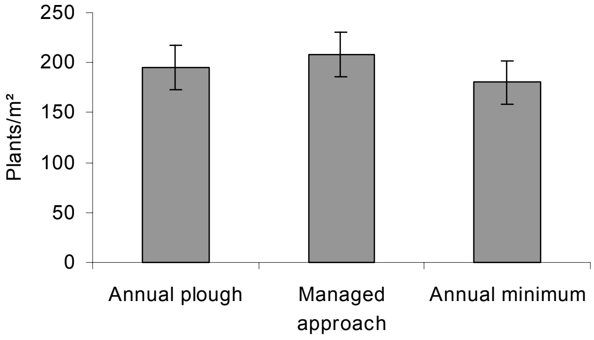


Figure 4-6. Effect of cultivation on wheat population at GS 13-14.

There was a strong negative relationship between wheat population and wheat heads counts (Figure 4-7).

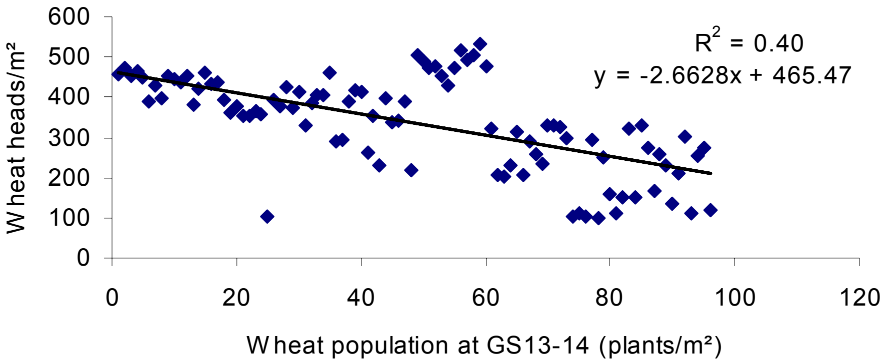


Figure 4-7. The relationship between winter wheat population and wheat head count.

4.2.6 *Yield*

Yield was averaged across all sites and all years as both sites responded similarly each year. Yield was significantly higher following the plough treatment ($P<0.05$) with the managed approach yield similar to the annual minimum cultivation (Figure 4-8). A full data set is available at Appendix 8-8.

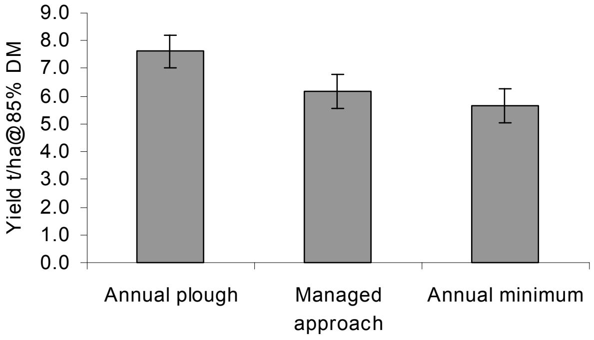


Figure 4-8. Effect of cultivation on winter wheat yield (% of overall mean).

There was a close positive relationship between winter wheat ear number and yield over all sites and years (Figure 4-9), but a negative one with black-grass head numbers (Figure 4-10).

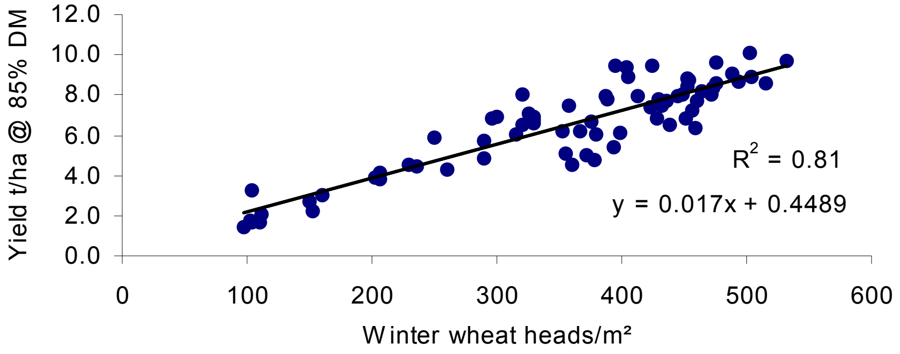


Figure 4-9. Relationship between wheat yield and wheat head count.

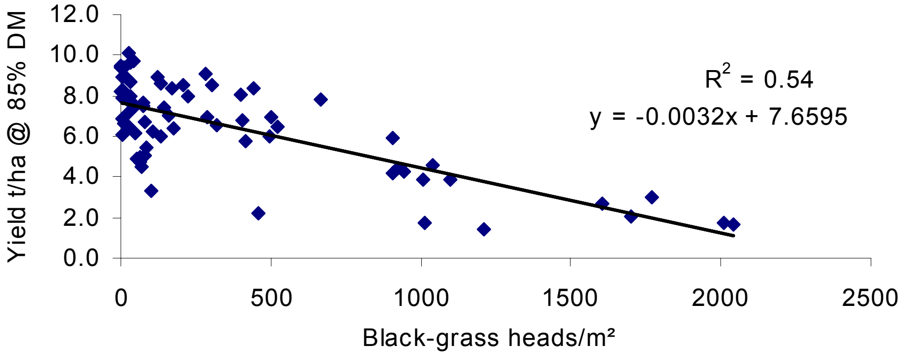


Figure 4-10. Relationship between wheat yield and black-grass population.

4.3 Discussion

The long-term trials were set up in order to manage black-grass populations over four years using the information developed within the project. Three treatments were used; annual plough, annual minimum cultivation and a managed approach. The managed approach would allow the site manager to modify treatments such as cultivation method, cultivation timing and drilling date using dormancy data from the research project as it developed. The results have shown that there has been some success in applying this knowledge as it emerged. At Boxworth, black-grass populations were kept under control successfully but meadow brome and wild-oat populations increased to put the site under great pressure. Managing for black-grass alone allowed brome and other grass weeds to increase, therefore a combined strategy is needed for mixed weed populations. At the Velcourt site, black-grass management was successful until a low dormancy situation in a very dry year. Here drilling date was delayed but there had not been sufficient rainfall to encourage emergence of the black-grass. Emergence then occurred after drilling. It will always be difficult to control black-grass in situations such as this as the weather cannot be predicted, but knowledge of dormancy can help prioritise fields for drilling.

5 CONCLUSIONS

5.1 Dormancy

- A test has been developed to determine dormancy level in black-grass seed collected in July.
- Temperature stress towards the end of seed maturation, irrespective of that during early stages of development, had the greatest impact on dormancy status. In natural black-grass populations, this critical timing was mid-June to mid-July under field conditions.
- A combination of increased mean maximum (1.8°C) and mean minimum (1.4°C) temperatures over the long-term average for mid-June to mid-July reduced the dormancy of black-grass seed. Temperature was correlated to solar radiation but negatively correlated to rainfall. Both of the years with temperatures below average resulted in higher levels of dormancy.
- Since temperature, which is consistent over large areas, is the major driver of dormancy levels in any given year, it should be possible to provide regional forecasts of seed dormancy based on a relatively small number of samples.
- The effect of a more-dormant population was to delay emergence of black-grass, compared to a less-dormant population by at least 6-8 weeks even in the presence of adequate soil moisture. The more-dormant population also had a greater number (up to 20%) of seeds still viable in the late autumn.
- The conclusions on dormancy in black-grass (20 samples per year) cannot be immediately applied to other grass species. Sampling in 2004 of a small number (up to eight samples) of Italian rye-grass, barren brome and meadow brome indicated there was greater variation in dormancy between these species but that in some, such as Italian rye-grass and barren brome, the dormancy lasted a shorter time than for black-grass. Further work would be required to be more specific in species other than black-grass.

5.2 Short-term trial

- High dormancy years

– In wet autumns with adequate moisture availability, high dormancy black-grass populations still showed delayed emergence.

– Drilling after 20 October resulted in significantly lower black-grass populations.

– If drilling before 20 October, ploughing resulted in the best reduction of high black-grass populations but this was not significant. At every site however, ploughing resulted in lower populations than discing.

- Low dormancy years

- There was no emergence of black-grass until there was adequate moisture. In small plot experiments, which were watered, we demonstrated that low dormancy populations were able to emerge immediately provided sufficient moisture was available
- Resulted in higher populations in the stubble and lower populations in the crop when assessed before the post-emergence spray.
- For any given cultivation regime there were no significant differences between before/after 20 October drilling dates, however, if drilling before 20 October, ploughing did result in significantly lower black-grass populations than discing before drilling or direct drilling. There was however a consistent trend, that for discing there were fewer black-grass present in the crop where cultivation took place immediately after harvest than before drilling

The following management matrix is an assimilation of the project findings in order to manage black-grass populations and not necessarily to maximise economic performance:

	Drilling date	
Dormancy**	Before 20 October*	After 20 October
High	**Not preferred**. When early drilling is essential, ploughing results in lowest levels of black-grass.	**Preferred.** Very much lower levels of black-grass. No difference between ploughing and discing.
Low	**Preferred**. If discing, cultivate immediately after harvest. Plough resulted in lowest levels of black-grass.	**Not preferred**. Ploughing resulted in lower levels of black-grass.

* earliest drilling date was 16 September, ** High dormancy is seed with less than 50% of seeds that will germinate immediately, Low dormancy is seed with more than 50% of seed that will germinate immediately.

5.3 Long-term trial

- Management of black-grass populations was enhanced by the use of dormancy information.
- The presence of a mixed grass-weed population made black-grass management more difficult, further work needs to further investigate dormancy patterns of other grass weed species.

6 ACKNOWLEDGEMENTS

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8 APPENDICES

Appendix 8-1. Short-term trial - Treatment dates and cultivations done at each site.

Site		ADAS Boxworth			Rothamsted		
Cropping year		2002-03	2003-04	2004-05	2002-03	2003-04	2004-05
Trial harvested		15-Aug-02	04-Aug-03	02-Sep-04	30-Aug-02	09-Aug-03	22-Aug-04
Post-harvest cultivations	plough	04-Sep-02	15-Aug-03	09-Sep-04	10-Sep-02	21-Aug-03	01-Sep-04
	Disc	04-Sep-02	15-Aug-03	14-Sep-04	10-Sep-02	20-Aug-03	01-Sep-04
Early non-selective herbicide		27-Sep-02	15-Sep-03	28-Oct-04	24-Sep-02	16-Sep-03	24-Sep-04
Early pre-drilling cultivation	plough	28-Sep-02	12-Sep-03	07-Oct-04	26-Sep-02	19-Sep-03	28-Sep-04
	Disc	30-Sep-02	12-Sep-03	07-Oct-04	26-Sep-02	19-Sep-03	28-Sep-04
Early drilling		30-Sep-02	16-Sep-03	01-Nov-04	26-Sep-02	19-Sep-03	29-Sep-04
Late non-selective herbicide		24-Oct-02	13-Oct-03	06-Dec-04	18-Oct-02 18-Dec-02	14-Oct-03	18-Oct-04
Late pre-drilling cultivation	plough	11-Dec-02	14-Oct-03	02-Dec-04	29-Oct-02	16-Oct-03	15-Nov-04
	Disc	07-Jan-03	14-Oct-03	02-Dec-04	29-Oct-02	16-Oct-03	15-Nov-04
Late drilling		07-Jan-03	14-Oct-03	15-Dec-04	10-Dec-02	17-Oct-03	14-Dec-04
Post-emergence spray (early drilling)		17-Feb-03	19-Nov-03	21-Mar-05	18-Dec-03	09-Dec-03	12-Apr-05
Post-emergence spray (late drilling)		09-May-03	19-Nov-03	21-Mar-05	08-Apr-03	09-Feb-04	12-Apr-05

Site		TAG			Velcourt		
Cropping year		2002-03	2003-04	2004-05	2002-03	2003-04	2004-05
Trial harvested		15-Aug-02	05-Aug-03	08-Sep-04	12-Aug-02	26-Aug-03	28-Aug-04
Post-harvest cultivations	plough	19-Aug-02	11-Aug-03	14-Sep-04	19-Aug-02	28-Aug-03	17-Sep-04
	Disc	22-Aug-02	11-Aug-03	14-Sep-04	19-Aug-02	28-Aug-03	20-Sep-04
Early non-selective herbicide		13-Sep-02	08-Sep-03	27-Sep-04	22-Aug-02	29-Sep-03	09-Oct-04
Early pre-drilling cultivation	plough	15-Sep-02	11-Sep-03	29-Sep-04	05-Sep-02	29-Sep-03	10-Oct-04
	Disc	15-Sep-02	09-Sep-03	29-Sep-04	05-Sep-02	29-Sep-03	10-Oct-04
Early drilling		16-Sep-02	13-Sep-03	07-Oct-04	05-Sep-02	30-Sep-03	10-Oct-04
Late non-selective herbicide		07-Oct-02	11-Oct-03	18-Oct-04	10-Sep-02	22-Oct-03	16-Nov-04
Late pre-drilling cultivation	plough	08-Oct-02	13-Oct-03	22-Oct-04	02-Oct-02	27-Oct-03	25-Nov-04
	Disc	09-Oct-02	14-Oct-03	22-Oct-04	02-Oct-02	27-Oct-03	25-Nov-04
Late drilling		10-Oct-02	14-Oct-03	17-Nov-04	02-Oct-02	28-Oct-03	25-Nov-04
Post-emergence spray (early drilling)		30-Oct-02	21-Oct-03	15-Apr-04	10-Sep-02	21-Nov-03	
Post-emergence spray (late drilling)		19-Nov-02	04-Dec-03	15-Apr-04	06-Oct-02	09-Dec-03	

Appendix 8-2. Method of seed sampling for dormancy status.

- Collect seeds from *winter wheat* fields in *second or third week of July* when about 10-30% seeds have already been shed.
- Do *not* collect when seeds are wet following rain - seeds can become very dormant.
- Collect ripe seeds by *gently* rubbing heads over a polythene bag, tray or envelope so only ripe seeds are detached. *Do not simply collect heads from the field or strip seeds as this will result in a poor quality sample*.
- Samples collected in the proper manner will consist almost entirely of seeds, with no stalks, chaff or other debris.
- Aim to collect over an area of about 100 m by 2 - 3 tramlines ideally (i.e. over a reasonable area)
- Quality is more important than quantity, but aim to collect the equivalent of at least a cupful to allow for losses during drying and cleaning. This should take less than 15 minutes.
- Beware of rapid heating of freshly collected samples. While collecting into a polythene bag is usually the most convenient way of collecting seeds, *do not store seeds in polythene bags.*
- Air dry seeds indoors as soon as possible after collection. Small samples can be dried in open trays or in envelopes by simply standing them on end with the flap open and shaking the envelope daily. Seeds should be dry within a few days. (*Practical tip: Use envelopes with end (not side) flaps, and staple side and bottom seams to prevent them coming unstuck due to moisture from seeds*).
    - record date of collection
    - field location (preferably map reference)
    - farm details and county
    - condition of crop, especially in relation to any drought stress at time of collection
    - an idea of infestation level (approx. heads per m^2)

Appendix 8-3. Soil sampling for seed bank assessment.

Timing and depth

Post-harvest, pre-cultivation

Depth	***Detail***
0 - 1 cm	Use soil sampling box and spade. Place box on soil surface and press into ground to a depth. Dig out 1cm using spade and place soil straw and seeds in the bag. Try and remove surplus straw making sure that no seeds are contained within it.
1 – 10 cm	Core sample from within middle of above box.
10 - 20 cm	Core sample from within middle of above box.

Post-winter; just as soil dries in spring

Depth	***Detail***
0 – 10 cm	Core sample.
10 - 20 cm	Core sample.

MATERIALS AND EQUIPMENT

- A hand held auger (cheese corer type) 25-30 mm diameter. The diameter of the auger used **must** be stated on labels or in accompanying sample documentation. The auger should be marked in some way to indicate the depth to which samples should be taken.
- Spatula or similar tool to remove soil from the auger.
- Heavy-duty polythene bags.
- Pre-prepared card labels, ideally these should be printed using a laser printer (minimum 14 point).
- Experiment site plan with a list of which plots are to be sampled.

PROCEDURES

1. Preparation

1.1 Prepare labels on card for each sample plot, ideally these should be printed using a laser printer (minimum 14 point). Samples must be double labelled (see SOP AGRON/024) and depending how this is being done you may need two sets of labels per plot/bag. Labels should include the study number, site, field, plot or quadrat, type of assessment and date. If more than one bag per sample is needed labels should indicate that the bag is only part of a sample and the total number of bags per sample.

1.2 Annotate a trial plan or append to a trial plan a list of the plots to be sampled.

2. Sampling

2.1 Take 20 samples from each ‘core’ area. Put into one bag, making sure each depth is in a different bag.

2.2 Within plots, cores should be sampled on a ‘stratified random’ basis i.e. cores should be taken from random positions, but from all areas of the plot. The best way to do this is to walk in a zigzag across the plot, taking cores every few paces (the distance between cores depends on the sampling intensity).

2.3 Where sampling from a very small area this will entail sampling from a quadrat of the specified size.

2.4 For each core, push the auger in to the required depth (the soil will compress to a greater or lesser extent but this is unavoidable) and extract as clean a core as possible. Try to avoid soil from the surrounding area falling into the corer and conversely soil from the corer falling out when the auger is removed.

2.5 Extract the soil from the auger using a spatula and avoid including soil, which is stuck to the outside of the auger.

2.6 When all cores from a sample have been collected, put the card labels in the bag(s) facing outwards, so that they can be read from outside the bag(s).

2.7 Where it is necessary to sample to two depths, push the corer in to the deepest depth and divide the core from the corer directly into the sample bags. Bear in mind that compression will be greater deeper down the profile.

3. Sample Storage

3.1 Samples should be stored frozen (c. –18°C) to prevent any seed germination. Where there is more than one bag per sample make sure that bags are stored together.

3.2 Samples should be sent to ADAS Boxworth for analysis when convenient for both parties. If not frozen at sample site, store in cool dark place and discuss with ADAS Boxworth how to get samples there as soon as possible for freezing.

4. Processing (ADAS Boxworth)

4.1 All soil samples to be weighed as soon as possible after collection. A small (<25 g) sub-sample to be taken from each soil sample, weighed, dried at 100°C for 24 hours and then reweighed. This information will be used to calculate the dry soil weight of each soil sample so that values for seed content can be corrected to account for differences in the amount of soil collected from different cultivation plots. This is likely due to differences in bulk density between cultivation treatments.

Appendix 8-4. Short-term trial - Assessment dates at each site.

a) Boxworth and Rothamsted

Site		Boxworth			Rothamsted		
Cropping year	Treatments	2002 -03	2003-04	2004-05	2002-03	2003-04	2004-05
Previous crop head count	All	26-Jul-02	18-Jul-03	12-Jul-04	14-Aug-02	4-Jul-03	29-Jun-04
Harvested	All	15-Aug-02	04-Aug-03	02-Sep-04	30-Aug-02	9-Aug-03	21-Aug-04
Prior to cultivation	All	2-Sep-02	11-Aug-03	7-Sep-04	2-Sep-02	13-Aug-03	25-Aug-04
Prior to spraying off and drilling	Early drilled	24-Sep-02	28-Aug-03	29-Sep-04	23-Sep-02	15-Sep-03	15-Sep-04
	Late drilled	18-Oct-02	8-Oct-03	1-Dec-04	17-Oct-02	13-Oct-03	18-Oct-04
	Late drilled*	11-Dec-02					
Prior to post-emergence spray	Early drilled	11-Dec-02	19-Nov-03	16-Feb-05	5-Dec-02	28-Nov-03	3-Nov-04
	Early drilled*	12-Feb-03					
	Late drilled	8-May-03	19-Nov-03	16-Feb-05	7-Apr-03	13-Jan-04	21-Mar-05
WW plant population GS 13-14	All	-	5-Feb-04	16-Feb-05	5-Dec-02 & 7-Apr-03	11-Nov-03 & 16-Dec-03	4-Jan-05 & 22-Mar-03
Crop and weeds prior to GS 30	Early drilled	20-May-03	Crop 5-feb-04, weeds 24-Mar-04	-	21-May-03	15-Mar-04	17-May-05
	Late drilled	20-May-03		-	9-Jun-03	30-Mar-04	17-May-05
Crop and weed head count	All	3-Jul-03	1-Jul-04, 29-Jul-04	-	9-Jun-03 & 24-Jun-03	16-Jun-04	-
Seedbank autumn	All	27-Aug-02	8-Aug-03	-	2-Sep-02	13-Aug-03	25-Aug-04
Seedbank spring	All	27-Mar-03	31-Mar-04	-	21-Mar-03	23-Mar-04	23-Mar-05

* Counts repeated due to delay in drilling date

b) TAG and Velcourt

Site		TAG			Velcourt		
Cropping year	Treatments	2002-03	2003-04	2004-05	2002-03	2003-04	2004-05
Previous crop head count	All	25-Jul-02	Not done	Not done	3-Jul-02	Not done	17-Jul-04
Harvested	All	15-Aug-02	5-Aug-03	8-Sep-04	12-Aug-02	26-Aug-03	28-Aug-04
Prior to cultivation	All	19-Aug-02	8-Aug-03	14-Sep-04	19-Aug-02	28-Aug-03	17-Sep-04
Prior to spraying off and drilling	Early drilled	12-Sep-02	8-Sep-03	27-Sep-04	22-Aug-02	29-Sep-03	9-Oct-04
	Late drilled	7-Oct-02	11-Oct-03	18-Oct-04	10-Sep-02	22-Oct-03	16-Nov-04
Prior to post-emergence spray	Early drilled	31-Oct-02	22-Oct-03	20-Dec-04	15-Jan-03	21-Nov-03	18-Mar-05
	Late drilled	20-Nov-02	2-Dec-03	26-Jan-05	-	9-Dec-03	-
WW plant population GS 13-14	All	23-Oct-02 & 20-Nov-02	-	20-Dec-04	-	21-Nov-03	-
Crop and weeds prior to GS 30	Early drilled	24-Mar-03	22-Mar-04	15-Apr-05	-	5-Apr-04	-
	Late drilled	24-Mar-03	22-Mar-04	15-Apr-05	-	-	-
Crop and weed head count	All	10-Jun-03	8-Jun-04	-	20-Jun-03	Not done	-
Seedbank autumn	All	-	8-Aug-03	14-Sep-04	3-Sep-02	5-Sep-03	-
Seedbank spring	All	-	22-Mar-04	-	2-Mar-03	15-Apr-04	-

Appendix 8-5. Short-term trial – data.

Code	Explanation	Code	Explanation
DC	Primary cultivation - Disc	A	Time of primary cultivation – immediately after harvest
P	Primary cultivation - Plough	B	Time of primary cultivation – up to one week before drilling
DD	Direct Drill	E	Target drilling date – early, before 15 September
		L	Target drilling date – late, after 15 September, or three weeks after early drilling

a) Black-grass counts in stubble (plants/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	97	121	64	94	16	6	17	353	98	243	14	3	484	186	129
DC/A/E	100	123	52	92	5	4	18	381	102	364	6	1	988	340	186
DC/B/L	90	199	40	109	20	4	14	343	95	853	7	3	663	381	203
DC/B/E	95	169	41	102	19	8	22	378	107	295	8	1	472	194	137
DD/L	119	182	37	112	37	13	19	396	116	649	5	2	737	348	200
DD/E	101	102	56	86	23	6	22	385	109	780	9	3	988	445	225
P/A/L	121	84	41	82	26	4	18	405	113	741	15	6	797	390	205
P/A/E	90	124	41	85	41	6	17	416	120	352	13	5	472	210	143
P/B/L	126	115	31	91	16	11	12	404	111	548	9	1	711	317	180
P/B/E	94	120	49	87	16	8	27	299	88	313	7	3	988	328	175
Mean	103	134	45	94	22	7	19	376	106	514	9	3	730	314	178

b) Black-grass counts before sowing and drilling (plants/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	161	258	185	201	2	8	101	419	132	2436	1960	20	85	1125	512
DC/A/E	128	212	14	118	0	0	26	71	24	2093	1111	0	60	816	338
DC/B/L	375	280	150	268	157	166	334	637	324	870	2205	25	0	775	473
DC/B/E	343	401	169	304	27	23	17	309	94	5775	4161	4	4	2486	1021
DD/L	301	262	136	233	196	250	114	617	294	1138	2468	16	369	998	533
DD/E	391	257	254	301	38	14	7	319	94	4082	3357	7	598	2011	848
P/A/L	40	96	50	62	0	3	19	15	9	1176	147	12	2	334	142
P/A/E	37	85	11	44	0	0	3	2	1	1007	199	0	57	316	127
P/B/L	380	257	137	258	110	209	193	644	289	1011	2700	18	0	932	514
P/B/E	360	424	157	314	30	21	22	356	107	1636	3945	8	0	1397	633
Mean	252	253	126	210	56	69	84	339	137	2122	2225	11	117	1119	514

c) Black-grass counts prior to the post-emergence spray (plants/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	20	102	841	321	35	10	236	1327	402	214	1239	9	3	366	367
DC/A/E	111	1745	587	815	95	44	257	2363	690	325	4977	21	96	1355	966
DC/B/L	14	122	731	289	30	32	1316	922	575	630	1133	9	7	445	450
DC/B/E	70	2029	731	944	74	80	523	2755	858	660	5567	11	124	1590	1148
DD/L	17	93	650	253	131	142	493	1553	580	382	1229	7	1	405	427
DD/E	187	1339	991	839	392	87	437	1469	596	724	4453	24	24	1306	920
P/A/L	3	66	344	138	24	2	84	570	170	107	144	15	1	67	124
P/A/E	24	1591	291	635	129	10	30	399	142	167	718	13	27	231	309
P/B/L	6	119	544	223	27	7	106	555	174	324	425	9	0	190	193
P/B/E	35	1515	135	562	27	11	118	1089	311	230	940	24	18	303	377
Mean	49	872	584	502	97	43	360	1300	450	376	2082	14	30	626	528

d) Black-grass counts at GS 30 (plants/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	-	20	21	20	2	5	30	24	15	155	209	9	-	124	53
DC/A/E	66	25	69	53	2	11	596	55	166	45	243	21	-	103	113
DC/B/L	-	32	10	21	4	4	442	19	117	192	276	9	-	159	110
DC/B/E	68	30	86	61	2	23	939	34	249	94	522	11	-	209	181
DD/L	-	19	11	15	6	11	113	71	50	192	284	7	-	161	79
DD/E	99	28	78	68	23	20	634	63	185	112	390	24	-	175	147
P/A/L	-	22	4	13	2	0	14	16	8	44	23	15	-	28	16
P/A/E	11	27	37	25	5	4	39	1	12	61	102	13	-	58	30
P/B/L	-	21	8	14	1	3	14	5	6	147	144	9	-	100	39
P/B/E	19	22	25	22	4	6	173	5	47	37	95	24	-	52	41
Mean	53	25	35	34	5	9	299	29	86	108	229	14	-	117	82

e) Winter wheat plant counts at GS13-14 (plants/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	66	135	148	116	211	185	201	-	199	22	55	209	-	96	137
DC/A/E	87	222	59	123	201	149	155	-	168	143	171	204	-	173	155
DC/B/L	45	19	103	56	258	173	168	-	200	23	55	163	-	80	112
DC/B/E	36	161	57	85	167	200	146	-	171	130	116	182	-	143	133
DD/L	39	106	53	66	195	188	9	-	131	7	51	122	-	60	86
DD/E	23	150	43	72	109	214	86	-	136	68	109	173	-	117	108
P/A/L	87	103	143	111	243	164	205	-	204	36	149	198	-	128	148
P/A/E	80	211	39	110	155	154	172	-	160	211	178	203	-	197	156
P/B/L	57	96	138	97	178	151	202	-	177	35	57	182	-	91	122
P/B/E	28	211	22	87	173	143	199	-	172	137	127	132	-	132	130
Mean	55	141	80	92	189	172	154	-	172	81	107	177	-	122	129

f) Winter wheat plant counts at GS 30 (plants/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	-	-	-	-	211	185	-	377	258	12	65	-	-	39	170
DC/A/E	-	-	-	-	201	149	-	171	174	99	149	-	-	124	154
DC/B/L	-	-	-	-	258	173	-	355	262	19	55	-	-	37	172
DC/B/E	-	-	-	-	167	200	-	197	188	95	98	-	-	96	151
DD/L	-	-	-	-	195	188	-	297	227	9	63	-	-	36	150
DD/E	-	-	-	-	109	214	-	155	159	49	69	-	-	59	119
P/A/L	-	-	-	-	243	164	-	341	249	36	128	-	-	82	182
P/A/E	-	-	-	-	155	154	-	135	148	100	137	-	-	119	136
P/B/L	-	-	-	-	178	151	-	370	233	36	62	-	-	49	159
P/B/E	-	-	-	-	173	143	-	193	170	70	81	-	-	76	132
Mean	-	-	-	-	189	172	-	259	207	52	91	-	-	72	153

g) Black-grass head counts (heads/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	439	50	49	179	3	197	494	-	231	255	709	0	259	306	246
DC/A/E	487	74	322	294	14	317	794	-	375	20	251	16	955	310	325
DC/B/L	651	61	39	250	6	178	660	-	281	241	624	1	324	298	278
DC/B/E	564	101	318	328	21	547	799	-	456	91	888	10	1037	506	438
DD/L	657	49	115	274	34	509	500	-	347	363	557	0	317	309	310
DD/E	598	39	380	339	81	332	457	-	290	118	833	36	663	412	354
P/A/L	99	28	5	44	11	6	421	-	146	128	10	0	208	87	92
P/A/E	302	64	166	177	5	113	451	-	190	72	156	2	801	258	213
P/B/L	351	39	9	133	4	128	497	-	210	176	315	0	258	187	178
P/B/E	249	105	94	149	1	92	735	-	276	68	242	4	547	215	214
Mean	440	61	149	217	18	242	581	-	280	153	459	7	537	289	265

g) Winter wheat head counts (heads/m²)

Year	2003				2004					2005					Mean
Site	Boxworth	Rothamsted	TAG	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	Boxworth	Rothamsted	TAG	Velcourt	Mean	
Treatment															
DC/A/L	223	164	360	249	441	236	173	-	283	131	190	416	-	246	259
DC/A/E	144	192	328	221	436	187	139	-	254	234	470	353	-	352	276
DC/B/L	137	49	336	174	443	216	133	-	264	113	212	384	-	237	225
DC/B/E	102	164	277	181	442	147	46	-	212	268	289	360	-	306	233
DD/L	99	212	249	187	446	185	51	-	227	48	257	405	-	237	217
DD/E	50	185	282	172	402	206	109	-	239	258	189	386	-	278	230
P/A/L	278	190	345	271	447	204	199	-	283	218	419	389	-	342	299
P/A/E	204	181	305	230	425	138	185	-	249	378	431	372	-	394	291
P/B/L	192	153	383	243	452	226	220	-	299	115	274	395	-	261	268
P/B/E	54	207	239	167	406	97	117	-	207	288	352	347	-	329	234
Mean	148	170	310	209	434	184	137	-	252	205	308	381	-	298	253

Appendix 8-6. Long-term trial - Treatment dates and cultivations done at each site.

Number	Description
1	Annual plough
2	Managed approach
3	Annual minimum cultivation

Site	Boxworth	Boxworth	Boxworth	Boxworth	Velcourt	Velcourt	Velcourt	Velcourt
Cropping year	2001-02	2002-03	2003-04	2004-05	2001-02	2002-03	2003-04	2004-05
Harvest date	22-Aug-01	16-Aug-02	12-Aug-03	26-Aug-04	31-Aug-01	16-Aug-02	14-Aug-03	4-Sep-04
Glyphosate application								19-Sep-04
Plough (Trt 1)	13-Sep-01	4-Aug-02	15-Aug-03	7-Oct-04	15-Sep-01	20-Sep-02	27-Aug-03	20-Sep-04
Primary cultivation date (Trt 2)	13-Sep-01	4-Aug-02	14-Oct-03	7-Oct-04	15-Sep-01	20-Sep-02	15-Sep-03	20-Sep-04
Primary cultivation implement(Trt 2)	Simba solo	Simba solo	Simba solo	plough	plough	Simba solo	scratch	plough
Primary cultivation date (Trt 3)	13-Sep-01	4-Aug-02	19-Aug-03	7-Oct-04	7-Oct-01	20-Sep-02	27-Aug-03	20-Sep-04
Primary cultivation implement (Trt 3)	Simba solo	Simba solo	Simba solo	Q-vone	Simba solo	Simba solo	Simba solo	Simba solo
Drill date (Trt 1&3)	3-Nov-01	30-Sep-02	16-Sep-03	5-Nov-04	12-Oct-01	27-Sep-02	3-Oct-03	11-Oct-04
Drill date (Trt 2)	3-Nov-01	30-Sep-02	14-Oct-03	5-Nov-04	12-Oct-01	27-Sep-02	3-Oct-03	11-Oct-04
Pre-drill spray date (Trt 1&3)	13-Oct-01	30-Sep-02	15-Sep-03	4-Nov-04	10-Oct-01	25-Sep-02	1-Oct-03	9-Oct-04
Pre-drill spray (Trt 2)	13-Oct-01	30-Sep-02	13-Oct-03	4-Nov-04	10-Oct-01	25-Sep-02	1-Oct-03	9-Oct-04
Pre-emergence spray (Trt 1&3)	15-Nov-01	7-Oct-02	24-Sep-03	Not applied	1-Nov-01	30-Sep-02	10-Oct-03	18-Oct-04
Pre-emergence spray (Trt 2)	15-Nov-01	7-Oct-02	24-Oct-03	Not applied	1-Nov-01	30-Sep-02	10-Oct-03	18-Oct-04
Post-emergence spray (All Trts)	14-Feb-02	20-Feb-03	8-Dec-03	21-Mar-05	20-Nov-01	26-Nov-02	4-Dec-03	Not applied

Appendix 8-7. Long term trial – assessment dates.

Site	Boxworth	Boxworth	Boxworth	Boxworth	Velcourt	Velcourt	Velcourt	Velcourt
Cropping year	2001-02	2002-03	2003-04	2004-05	2001-02	2002-03	2003-04	2004-05
% non-dormant	40	38	47	24	80	41	81	26
Seedbank (autumn)	12-Sep-01	20-Aug-02	15-Aug-03	1-Sep-04	31-Aug-01	16-Aug-02	14-Aug-03	16-Sep-04
Count prior to cultivation	4-Sep-01	20-Aug-02	14 -Aug-03 (Trt 1&3) 8-Oct-03 (Trt 2)	1-Sep-04	31-Aug-01	16-Aug-02	14-Aug-03	16-Sep-04
Count prior to spraying off and drilling	8-Oct-01	24-Sep-02	14-Oct-03 (Trt 2) 14-Sep-03 (Trt 1&3)	5-Oct-04	11-Oct-01	27-Sep-02	3-Oct-03	1-Oct-04
Repeat count due to delay in drilling							22-Oct-03	
Count prior to post-emergence spray	18-Dec-01	9-Jan-03	8-Dec-03	16-Feb-05	3-Dec-01	26-Nov-02	4-Dec-03	13-Apr-05
Count prior to post-emergence spray (repeat due to delayed drilling)	12-Feb-02	25-Feb-03	-	-	-	-	-	-
WW plant population GS 13-14	24-Jan-02	25-Feb-03	5-Feb-04	21-Jan-05	-	-	-	13-Apr-05
Crop and weeds prior to GS 30	7-May-02	15-May-03	24-Mar-04	23-May-05	30-Apr-02	31-Mar-03	-	13-Apr-05
Crop and weed head count	12-Jul-02	1-Jul-03	1-Jul-04	13-Jul-05	26-Jun-02	23-Jun-03 BG only	2-Jun-04	13-Jun-05
Yield of grain	16-Aug-02	12-Aug-03	26-Aug-04	not done	15-Aug-02	14-Aug-03	4-Sep-04	not done
Seedbank (spring)	2-Apr-02	25-Mar-03	26-Mar-04	5-Apr-05	18-Apr-02	31-Mar-03	24-Mar-04	13-Apr-05

Appendix 8-8. Long-term trial – data.

a) Stubble counts (plants/m²)

Site	Treatment	Year 2002	2003	2004	2005	Mean
Boxworth	Annual plough	773	1	9	0	196
	Managed approach	603	4	127	4	185
	Annual minimum cultivation	356	2	20	37	104
Velcourt	Annual plough	62	3	0	656	180
	Managed approach	51	2	0	1322	344
	Annual minimum cultivation	89	3	0	1351	361

b) Pre-sowing and drilling (plants/m²)

Site	Treatment	Year 2002	2003	2004	2005	Mean
Boxworth	Annual plough	331	56	0	4	98
	Managed approach	381	61	0	4	111
	Annual minimum cultivation	294	69	0	7	92
Velcourt	Annual plough	51	0	0	6	14
	Managed approach	53	0	901	7	240
	Annual minimum cultivation	299	0	91	911	325

c) Pre-post-emergence spray (plot) (plants/m²)

Site	Treatment	Year 2002	2003	2004	2005	Mean
Boxworth	Annual plough	10	8	16	23	14
	Managed approach	84	48	458	18	152
	Annual minimum cultivation	40	33	969	89	283
Velcourt	Annual plough	60	37	174	12	71
	Managed approach	81	131	1270	8	372
	Annual minimum cultivation	235	165	793	455	412

d) Pre-post-emergence spray (shield area – no pre-emergence applied, plants/m²)

Site	Treatment	Year 2002	2003	2004	2005	Mean
Boxworth	Annual plough	160	51	48	23	71
	Managed approach	383	141	706	18	312
	Annual minimum cultivation	243	123	1175	89	407
Velcourt	Annual plough	98	225	1000	1000	581
	Managed approach	160	466	1750	1000	844
	Annual minimum cultivation	153	433	1625	1000	803

e) Count at GS30 (plot) (plants/m²)

		Year				
Site	Treatment	2002	2003	2004	2005	Mean
Boxworth	Annual plough	3	16	6	11	9
	Managed approach	13	52	280	7	88
	Annual minimum cultivation	26	39	88	6	40
Velcourt	Annual plough	19	8	-	68	32
	Managed approach	17	38	-	85	47
	Annual minimum cultivation	32	34	-	176	81

f) GS 30 (shield area – no pre-emergence applied, plants/m²)

		Year				
Site	Treatment	2002	2003	2004	2005	Mean
Boxworth	Annual plough	119	16	6	No pre-emergence applied	47
	Managed approach	187	52	280		173
	Annual minimum cultivation	198	39	88		108
Velcourt	Annual plough	43	44	-		43
	Managed approach	65	68	-		67
	Annual minimum cultivation	85	64	-		75

g) Black-grass heads (plants/m²)

		Year				
Site	Treatment	2002	2003	2004	2005	Mean
Boxworth	Annual plough	10	81	5	6	25
	Managed approach	21	107	27	1	39
	Annual minimum cultivation	23	76	75	14	47
Velcourt	Annual plough	194	431	509	389	380
	Managed approach	207	803	1858	498	841
	Annual minimum cultivation	307	798	1095	2000	1050

h) Winter wheat at GS 13-14 (plants/m²)

		Year				
Site	Treatment	2002	2003	2004	2005	Mean
Boxworth	Annual plough	237	133	156	349	219
	Managed approach	240	178	191	333	235
	Annual minimum cultivation	255	168	178	289	222
Velcourt	Annual plough	149	-	-	59	104
	Managed approach	157	-	-	61	109
	Annual minimum cultivation	111	-	-	31	71

i) Winter wheat head (heads/m²)

		Year				
Site	Treatment	2002	2003	2004	2005	Mean
Boxworth	Annual plough	458	391	407	371	407
	Managed approach	419	400	409	388	404
	Annual minimum cultivation	447	384	274	252	339
Velcourt	Annual plough	491	314	292	261	339
	Managed approach	496	257	129	273	288
	Annual minimum cultivation	468	243	118	134	241

j) Wheat yield (t/ha @ 85% DM)

Average of yield		year				
Site	Treatment	2002	2003	2004	2005	Mean
Boxworth	Annual plough	7.8	6.5	9.3	Not harvested	7.9
	Managed approach	7.6	5.7	7.5		6.9
	Annual minimum cultivation	7.7	6.1	5.0		6.3
Velcourt	Annual plough	8.8	6.3	6.9	Not harvested	7.3
	Managed approach	9.1	4.9	2.3		5.4
	Annual minimum cultivation	8.5	4.8	1.8		5.1