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New strategies to maintain autumn grass-weed control in cereals and oilseed rape.

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1. ABSTRACT

Effective grass weed control is essential if rotations of mainly autumn-sown crops are to be maintained. In future scenarios greater reliance will be placed on fewer herbicides due to increasing herbicide resistance, the absence of any new modes of action and the potential loss of key herbicides arising through the Water Framework Directive and other EU legislation. New weed control strategies need to focus on herbicides that are applied pre- or early post-emergence. The immediate concern that the Industry faces is therefore maintaining effective strategies based on remaining herbicides, but avoiding exacerbating resistance or pollution issues. This research project has ostensibly developed approaches to 'stacking' (applying more than one active ingredient or herbicide product at the same time) and 'sequencing' (when different active ingredients or mixtures of active ingredients are applied in close succession) techniques to deliver effective grass weed control and make best use of the options available. Research has specifically addressed the control of black-grass (*Alopecurus myosuroides*) and barren (sterile) brome (*Anisantha sterilis*) in cereals, black-grass in oilseed rape and annual meadow-grass (*Poa annua*) in cereals. With regard to the management of black-grass in winter wheat this has been done without the use of iodosulfuron-methyl-sodium + mesosulfuron-methyl (Atlantis, Bayer CropScience) where grass weed resistance is a developing issue. Research has developed approaches suited to a range of scenarios. Considering black-grass in oilseed rape findings highlight the continued importance of propyzamide and carbetamide and outline routes to help maximise their performance. Considering grass weed control in cereal crops, several active ingredients remain key to managing both barren brome and black-grass, notably flufenacet but also prosulfocarb and tri-allate (several other active ingredients have also delivered useful contributions to 'stack' and 'sequence' approaches). Data suggests that 'stack' and 'sequence' approaches can improve the robustness of the weed control strategies; with generally at least 3 active ingredients being needed in the more successful approaches. For barren brome control in winter wheat, particularly in high pressure situations, a robust programme involving a residual herbicide and ALS inhibitor (i.e. herbicides targeting the acetolactate synthase (ALS) enzyme) components is likely to be required. Research considering black-grass in cereals has developed a series of stacking and sequencing approaches however, data suggests where populations in untreated plots exceed approximately 100 heads m^{-2} control offered through stacking and sequencing approaches is unlikely to offer >95% reductions in black-grass heads. In all scenarios, where grass weed populations are high non-chemical management practices should also be considered.

2. SUMMARY

Effective control of grass weeds in the autumn is fundamental to the delivery of rotations comprising mainly autumn sown crops. In the future it is likely that in order to deliver effective grass weed control greater reliance will need to be placed on fewer herbicides, due to increasing herbicide resistance, the absence of any new modes of action and the potential loss of key herbicides under the Water Framework Directive and other EU legislation. The immediate concern that the Industry faces is therefore maintaining effective weed control strategies based on remaining herbicides, but avoiding exacerbating resistance or pollution issues. HGCA Research Review 70 indicated that a projected industry loss from black-grass (*Alopecurus myosuroides*) due to potential product withdrawals arising from (or following) 91/414/EEC could be around £185 million p.a. while product losses due to the Water Framework Directive could cost in excess of £500 million p.a.; the review indicated that losses from other grass-weeds would also be appreciable. Research within this project has specifically addressed the development of 'New strategies to maintain autumn grass-weed control in cereals and oilseed rape' in relation to the control of black-grass and barren or sterile brome (*Anisantha sterilis*) in cereals, black-grass in oilseed rape and meadow grass (*Poa annua*) in cereals. Field trials were conducted through NIAB TAG and SAC (now known as SRUC) over 4 seasons in harvest years 2008, 2009, 2010 and 2011 at a range of locations in England and Scotland. Fully replicated field experiments were generally undertaken in 'farm crop' established in accordance with local best practice and were located in situations where a high burden of the desired problem weed was anticipated. Approaches have ostensibly sought to develop 'stacking' (applying more than one active ingredient or herbicide product at the same time) and 'sequencing' (when different active ingredients or mixtures of active ingredients are applied in close succession) techniques. It should be noted that treatments outlined within this report are not necessarily currently approved for use in the crops and scenarios described. This is either due to experimental use of materials to examine their suitability or changes in approval since the research was undertaken (for example chlorotoluron was used in this project as a separate product and it is now only available in co-formulation with diflufenican). A summary of key findings is presented beneath.

2.1 Annual meadow grass (cereals)

Approaches for the control of annual meadow-grass have tended to historically include isoproturon (IPU); in these studies isoproturon delivered, on average, a 95% reduction in the ground cover of annual meadow grass. However, a range of other currently available herbicides also delivered similar, or superior, levels of control across a wide range of application timings (ranging from pre-emergence through to a 2-3 leaf stage of the weed). Many of these approaches will require a modification to timing compared to isoproturon, however they do demonstrate dose flexibility and, in addition to controlling annual meadow grass, many are also capable of delivering useful control of a range of broad-leaved weeds. Pre-emergence programmes including (but not limited to) the active ingredients flufenacet (e.g. in Liberator, Firebird and other herbicides), prosulfocarb (Defy) and pendimethalin (various products) have tended to be among the stronger performing approaches and also demonstrate useful dose flexibility providing a range of cost options to growers. Many of these materials are also suited to peri- or early post emergence use. Post emergence active ingredients such as chlorotoluron (subject to varietal suitability) and flumioxazine (e.g. Guillotine) can still also deliver useful levels of control. For later post emergence control, ALS inhibitor based products (or co-formulations) such as diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl (Othello) can provide effective control and will also provide useful control of other weeds. While research addressing the management of annual meadow grass was only undertaken in winter wheat, where products are approved it could be expected that control in winter barley should be comparable.

2.2 Barren Brome (winter barley)

Across a range of treatments for the control of barren brome in winter barley ‘stack’ and ‘sequence’ approaches tended to deliver higher levels of control compared to the use of single actives ingredients or timings; even at low populations. However, findings do suggest that where a brome population of greater than (approximately) 10–15 plants m^{-2} were present in the spring even the more effective programmes struggled to deliver in excess of 80% reduction in brome heads (fertile tillers). This is perhaps not unexpected given that the herbicides available for brome control in winter barley are limited to autumn applied residual herbicides. Strong spring crop competition in barley is also likely to be important. Where brome populations are high non-chemical management practices should also be considered.

The active ingredient flufenacet was common to many of the more effective barren brome control programmes in winter barley and incremental reduction in heads was found in response to increased dose. Tri-allate (Avadex Excel) also gave useful levels of control of barren brome, although typically less than that delivered by flufenacet based approaches. Of the other herbicide options examined, both flurtamone + diflufenican (Graduate) and chlorotoluron (on suitable varieties) tended to be insufficient to deliver effective control alone, however, their contribution within wider programmes and ‘stack’ and ‘sequence’ approaches was noteworthy. The range of herbicides examined provides growers with potentially valuable options to deliver suitable ‘stacking’ and ‘sequencing’ programmes for the management of barren brome in winter barley.

2.3 Barren brome (winter wheat)

Research within this experimental series suggests that 'stack' and 'sequence' approaches can deliver higher levels of barren brome control compared to the use of single actives ingredients or timings. Such approaches are key to reducing the number of barren brome plants / heads where brome pressure is high. The active ingredients tri-allate (Avadex Excel), flufenacet (e.g. in Liberator, Firebird and other herbicides), prosulfocarb (Defy) and chlorotoluron (various products) tended to feature among the more effective autumn options. As with barren brome control in winter barley, the active ingredient flufenacet was common to many of the more effective programmes and increasing control was apparent in response to incremental dose. Avadex Excel (tri-allate) also gave useful levels of control of barren brome across a range of weed pressures, particularly when used in 'stack' and 'sequence' approaches. Chlorotoluron (on suitable varieties) can also provide useful control when used in 'stack' and 'sequence' approaches.

The use of suitable ALS inhibiting products with a label recommendation for brome (e.g. products containing pyroxsulam or iodosulfuron-methyl-sodium + mesosulfuron-methyl) were particularly effective. In low pressure barren brome scenarios the use of an ALS inhibitor product alone or the use of a suitable autumn residual herbicide programme can substantially reduce brome head numbers and deliver acceptable control. However, in higher pressure situations robust programmes, generally involving residual herbicide and ALS inhibitor components are required. There are a range of 'stack' and/or 'sequence' options and cost structures available to deliver effective control of barren brome in these scenarios. In very high pressure scenarios it is likely that even intensive herbicide programmes may not reduce populations to a level that would not compromise yield; additional none chemical control routes will be required in these situations.

2.4 Black-grass (oilseed rape)

The choice of residual grass weed herbicides for oilseed rape is becoming increasingly limited and there is concern over water pollution arising from the use of some key active ingredients. However, the crop presents a key opportunity for black-grass management; not least because carbetamide (e.g. Crawler) and propyzamide (e.g. Kerb Flo) are not affected by resistance. Metazachlor (Butisan S and others) have traditionally been key pre- and early post emergence herbicides for use in oilseed rape, however, restrictions on cumulative use are being imposed. Research within this programme has evaluated other options for use in this window, specifically napropamide (Devrinol T) and tri-allate (Avadex Excel). When used alone performance of these products can vary but, when used at commonly applied doses, they delivered similar control of black-grass plants to Butisan S (averaging around 40–45% control). While 'stacking' and sequencing' these materials can improve the percentage control achieved, in general control levels have still typically been inferior to the most effective control programmes based around propyzamide (Kerb Flo and others) and/or carbetamide (Crawler and others); clearly demonstrating their continued importance. Research undertaken with propyzamide and carbetamide indicates that both timing and dose are important in maximising performance. Increasing control was associated with higher doses but research also suggests that with propyzamide a reduced dose at a time conducive to good efficacy can be as effective as a higher dose at a less favourable time. This could have important implications for managing both black-grass populations and the potential movement of herbicides to water. In general carbetamide demonstrates greater timing flexibility while propyzamide shows greater dose flexibility; where these products are to be used in sequence carbetamide should be used first. With regard to maximising overall black-grass control the strongest approaches tended to be the use in 'stack' or 'sequence' approaches. For example an appropriately timed autumn residual (such as propyzamide and/or carbetamide) with other herbicides (e.g. in a sequence with a metazachlor based product, although other options could be used). Weed pressure will have strong bearing on the cost of achieving effective black-grass control in oilseed rape. However, the opportunity afforded by propyzamide or carbetamide to manage resistant black-grass can contribute the strategy to manage this weed across the rotation (not just in the oilseed rape crop) and should be considered within this.

2.5 Black-grass (winter barley)

Herbicide approaches for the management of black-grass in winter barley are similar to those used in winter wheat (mainly with the exception of post emergence options based on ALS inhibitor materials). This places a strong reliance on autumn applied residual herbicides. With regard to autumn residual herbicides research in this series suggests that treatments involving flufenacet (a constituent of both Crystal and Liberator) tended to give the higher levels of black-grass control and that this control stemmed ostensibly from the flufenacet component of these materials. Prosulfocarb (Defy) used alone generally delivered lower levels of control compared to flufenacet based products, however, where it was used pre-emergence in conjunction with pendimethalin or used alone at an early post emergence stage levels of black-grass control similar to flufenacet based products were achieved; providing an alternative to flufenacet based approaches. Data also indicates tri-allate (Avadex Excel) to be a useful material for black-grass control programmes in winter barley. In general the more robust black-grass management programmes in winter barley involved 'stack' and 'sequence' approaches; such approaches generally deliver higher levels of control compared to the use of single actives ingredients or timings. While flufenacet featured commonly in approaches delivering higher levels of control, the following active ingredients have also featured; prosulfocarb, tri-allate, chlorotoluron (various products), pinoxaden (e.g. Axial), diflufenican (e.g. Hurricane) and flurtamone (e.g. Graduate). ‘Stacking’ and ‘sequencing’ approaches in winter barley can deliver in excess of 90% control of black-grass heads at untreated populations of around 100 heads m^{-2} (this is analogous to findings in winter wheat). There are a range of options and cost structures available to deliver black-grass control and programme selection will be influenced by specific scenarios. Many of the materials highlighted will also provide useful control of other grass (e.g. annual meadow grass) and broad-leaf weeds. Where black-grass pressure is high, consideration should also be given to cultural control options.

2.6 Black-grass (winter wheat)

Black-grass populations in winter wheat are becoming more difficult to control due to increasing herbicide resistance and reducing herbicide availability. Research within this programme has sought to develop further alternative approaches based around ‘stacking’ and ‘sequencing’ of available herbicides (or combinations of the two routes) without the use of iodosulfuron-methyl-sodium + mesosulfuron-methyl (Atlantis). The degree of control of heads achieved through these routes is associated with the size of the black-grass infestation and higher levels of control can only be achieved in low to moderate populations. Findings suggest that where populations in untreated plots exceed approximately 100 heads m^{-2} (possibly 10–15 surviving plants m^{-2}) the level of control offered through stacking and sequencing approaches is unlikely to offer >95% reductions in black-grass heads. In high black-grass pressure situations even intensive programmes are unlikely to reduce populations to commercially acceptable levels and additional cultural control routes will be required.

With regard to specific approaches, pre- and early post emergence herbicide options based on flufenacet (e.g. Crystal and Liberator) tended to give the higher levels of black-grass control (with data suggesting that control is ostensibly derived from the flufenacet component). Tri-allate (Avadex Excel) can also deliver similar levels of control. Prosulfocarb (Defy) used alone generally delivered lower levels of control however, where it was used pre-emergence in conjunction with pendimethalin or used alone at an early post emergence stage control improved (to similar to tri-allate and flufenacet based products). However, it is clear that the use of pre-emergence herbicides alone is unlikely to deliver adequate control and combinations through ‘stacks’ and ‘sequences’ will be required in most scenarios. Within the experimental series a variety of ‘stack’ and ‘sequence’ approaches have been explored and a range of routes demonstrated to deliver acceptable black-grass control; generally at least 3 active ingredients were needed in the more successful approaches. Flufenacet is an important component (incremental doses of this active have been shown to improve the control of black-grass); however, over reliance on any single active ingredient is of concern and approaches have also demonstrated non flufenacet based routes, such as those based around tri-allate (Avadex Excel) and prosulfocarb (Defy). A range of other active ingredients have also featured in specific ‘stack’ and ‘sequence’ approaches, including (but not limited to) chlorotoluron (various products and subject to varietal restrictions), flurtamone (e.g. Graduate) and diflufenican (e.g. Hurricane). These approaches also resulted in a high percentage reduction in black-grass heads even where ALS resistance (resistance to Atlantis) was present. This suggests that effective control is possible where resistance results in little or no contribution from ALS inhibitor products such as Atlantis. Research has shown little difference between ‘stack’ and ‘sequence’ approaches. However, at times, it may be expected that a ‘sequence’ of the same products will be more effective if the components are applied in conditions conducive to herbicide activity. For example in dry conditions treatments based on tri-allate (Avadex Excel) have been shown to more successful in relative terms.

The use of ‘stacking’ and ‘sequencing’ approaches will require an alteration to herbicide strategy for many growers. Specifically the strong reliance on residual herbicides applied pre- or early post emergence will require materials to be applied either before or at early stages of black-grass emergence. ‘Stacking’ and ‘sequencing’ techniques can also provide useful control of other grass (e.g. annual meadow-grass) and broad-leaf weeds. The specific costs of ‘stacking’ and ‘sequencing’ will be influenced by the products used and the deals through which they are purchased. Such approaches in many cases are likely to be more expensive than established strategies for many growers however wider farm adoption has become more common since autumn 2009.

3. TECHNICAL DETAIL

3.1 Introduction

Effective control of annual grass weeds in the autumn is fundamental to rotations comprising mainly autumn sown crops and is essential if these rotations are to be maintained. In the future it is likely that in order to deliver effective grass weed control greater reliance will need to be placed on fewer herbicides, due to increasing herbicide resistance, the absence of any new modes of action imminently available and the potential loss of key herbicides under the Water Framework Directive and other EU legislation.

New weed control strategies will need to give greater emphasis to the use of cultural control approaches in combination with herbicides that are applied pre-, peri- (during), or early post-emergence; when the majority of the remaining available products are most effective and enhanced metabolism resistance effects are minimised. New strategies however should not increase reliance on herbicides where resistance or detection in water, are a problem or are considered a threat.

Quantifying the potential impact of herbicide losses HGCA Research Review 70 (Pesticide availability for cereals and oilseeds following revision of Directive 91/414/EEC; effects of losses and new research priorities) indicated that total projected industry loss from black-grass (*Alopecurus myosuroides*) under losses initiated from (or following) 91/414/EEC could be around £185 million p.a. while product losses due to the Water Framework Directive could cost in excess of £500 million p.a.; the review indicated that losses from other grass-weeds would not be as massive however they would still be appreciable (for example under the same scenario losses due to annual meadow-grass (*Poa annua*) could be of the order of £40-90 million p.a.).

Considering this at the farm level, black-grass infests around half of the winter wheat area in the UK with resistance confirmed in 31 counties (Moss *et al.,* 2005) and on around 80% of farms sprayed for this weed (Moss *et al.,* 2011). Enhanced metabolism resistance is now considered to be extremely widespread within black-grass populations nationally, while target site resistance to ACCase inhibitor herbicides (e.g. fops, dims and dens) is estimated to occur in over 75% of field stocks and resistance to ALS inhibitor herbicides (e.g. iodosulfuron-methyl-sodium + mesosulfuron-methyl, Atlantis) is considered to be spreading rapidly and has already been found in 26 counties (Moss *et al.,* 2011). Currently ALS inhibitor and ACCase inhibitor herbicides account for 1 in 3 grass-weed active herbicides applied to UK crops (Garthwaite *et al.,* 2007). This progression reinforces the need to re-evaluate grass weed strategies and to develop systems that make best use of the material available.

However recent research by Moss & Hull (2009) is already suggesting that some of our more effective pre-emergence herbicides, such as flufenacet, have the potential to succumb to resistance and care needs to be taken to preserve their efficacy.

The immediate concern that the Industry faces is therefore maintaining effective and cost-effective herbicide strategies based on remaining herbicides, but avoiding an increased reliance on active ingredients where resistance development or detection in water are already a problem or a concern. New strategies need to specifically address approaches targeting the limited range of effective alternatives for the control of black-grass in cereals and oilseed rape, the increasing incidence of resistance in black-grass to ALS inhibitor based herbicides and the growing concern over water pollution issues (arising from herbicide use).

For more difficult grass weeds such as black-grass and sterile brome (Anisantha sterilis), a single pre- or early-post emergence herbicide treatment is rarely sufficient for adequate control, especially at high populations, and it will be necessary to develop reliable strategies for building treatment programmes through mixtures or close sequences of herbicides that are applied pre- or early post-emergence. In addition there is a need to re-evaluate the control of other grasses, such as annual meadow-grass (*Poa annua*). Prior to its withdrawal isoproturon (IPU) had been a key element of many programmes for the control of annual meadow grass in cereals. However, a range of products associated with the control of black-grass and sterile brome are potentially suitable, but have historically not been widely used due to lack of information on appropriate doses; these products are likely to become more important in future scenarios.

3.2 Materials and methods

Field trials were conducted over 4 seasons in harvest years 2008, 2009, 2010 and 2011. Studies were conducted through NIAB TAG and SAC (now known as SRUC) staff and were carried out across a range of locations in England and Scotland. The specific crop and weed combinations pursued within project 3341 are presented in Table 1. Research addressing annual meadow grass was only undertaken in years 1 (2008) and 2 (2009) of the project.

Table 1. Crop and weed combinations addressed within project 3341.

	Crop species		
Weed species	**Winter wheat**	**Winter barley**	**Winter oilseed rape**
Black-grass	✔	✔	✔
Barren brome	✔	✔	
Annual meadow grass	✔		

Field experiments were generally undertaken in ‘farm crop’ established in accordance with local best practice and were located in situations where a high burden of the desired problem weed was anticipated. The only exception to this were some of the barren brome studies which were sown with brome in order to ensure an even weed population. It should be noted that treatments outlined within this report are not necessarily currently approved for use in the crops and scenarios described. This is either due to experimental use of materials to examine their suitability or changes in approval since the research was undertaken (for example chlorotoluron was used in this project as a separate product and it is now only available in co-formulation with diflufenican).

All experiments were of a randomised complete block design with three replicates. All treatments were applied using a knapsack boom sprayer at 200 L ha^{-1} spray volume using flat fan nozzles. The products used and their active ingredients are outlined in Table 2. Specific programmes for each crop and weed combination in each season are presented in Appendix A. Application timings are either described as a date or a growth stage for treatment and generally refer to the crop (although crop and grass weed would be similar). Where growth stages refer specifically to the weed this highlighted in the relevant Tables and in Appendix A, similarly specific treatment dates (and other assessments details) are either outlined in outlined in the relevant results section or in Appendix B.

Testing for resistance to herbicides undertaken across the project suggest that herbicide resistance to fops, dims and CTU were was common across the trial series. Resistance to ALS inhibitor material only became apparent in the latter two seasons on specific sites. Further details and impacts on field performance are highlighted in the text where relevant in sections 3 and 4.

Where the term ‘stacking’ is used in this report it is taken to denote a technique whereby for a given target weed more than one active ingredient (or herbicide product) is applied at the same time (this can be achieved either through mixtures or applying products that contain more than one active ingredient). Sequencing is when different active ingredients or mixtures of active ingredients are applied in close succession. The two techniques are not mutually exclusive.

Table 2. *List of active ingredients and commercial products used within treatments.*

Active ingredient(s)	Active content	Formulation	Product name (or example of)	Manufacturer
carbetamide	60 % w/w	WG	Crawler	Makhteshim
chlorotoluron	500 g L^{-1}	SC	Various	-
clodinafop-propargyl	240 g L^{-1}	EC	Topik	Syngenta
clomazone	360 g L^{-1}	CS	Centium 360SC	Belchim
cycloxydim	200 g L^{-1}	EC	Laser	BASF
diflufenican	500 g L^{-1}	SC	Hurricane	Makhteshim
diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 + 2.5 + 7.5 g L^{-1}	OD	Othello	BayerCropScience
dimethachlor	500 g L^{-1}	EC	Teridox	Syngenta
diquat	200 g L^{-1}	SL	Reglone	Syngenta
ethofumesate	500 g L^{-1}	SC	Various	-
florasulam + pyroxsulam	1.42 + 7.08% w/w	WG	Broadway Star	Dow AgroSciences
flufenacet	600 g kg^{-1}	WG	-	-
flufenacet + diflufenican	400 + 100 g L^{-1}	SC	Liberator	BayerCropScience
flufenacet + diflufenican	400 + 200 g L^{-1}	SC	Firebird	BayerCropScience
flufenacet + metribuzin	24 + 17.5% w/w	WP	Artist	BayerCropScience
flufenacet + pendimethalin	60 + 300 g L^{-1}	EC	Crystal	BASF
flumioxazine	300 g L^{-1}	SC	Guillotine	Interfarm
flupyrsulfuron-methyl	50% w/w	WG	Lexus	DuPont
flurtamone + diflufenican	400 + 80 g L^{-1}	SC	Graduate	BayerCropScience
flurtamone + diflufenican	250 + 100 g L^{-1}	SC	Bacara	BayerCropScience
iodosulfuron-methyl-sodium + mesosulfuron-methyl	6 + 30 g kg^{-1}	WG	Atlantis WG	BayerCropScience
iodosulfuron-methyl-sodium + mesosulfuron-methyl	2 + 10 g L^{-1}	OD	Horus	BayerCropScience
iodosulfuron-methyl-sodium + mesosulfuron-methyl	1.0% + 3.0% w/w	WG	Pacifica	BayerCropScience
isoproturon	500 g L^{-1}	SC	Various	-
isoxaben + terbuthylazine	75 + 420 g L^{-1}	SC	Skirmish	Syngenta
metazachlor	500 g L^{-1}	SC	Butisan S	BASF
napropamide	450 g L^{-1}	SC	Devrinol	United Phosphorus
pendimethalin	330 g L^{-1}	EC	Various	-
pendimethalin + picolinafen	330 + 7.5 g L^{-1}	SC	Flight	BASF
pinoxaden	100 g L^{-1}	EC	Axial	Syngenta
propyzamide	400 g L^{-1}	SC	Kerb Flo	Dow AgroSciences
prosulfocarb	800 g L^{-1}	EC	Defy	Syngenta
sulfosulfuron	80% w/w	WG	Monitor	Monsanto
tri-allate	15% w/w	Granule	Avadex Excel	Gowan
trifluralin	480 g L^{-1}	EC	Alpha Trifluralin	Makhteshim

3.3 Results

3.3.1 Annual Meadow Grass

Field experiments looking at the control of annual meadow grass were undertaken in harvest years 2008 and 2009. Table 3 summarises details of the treatments applied and the timing of assessments (see Appendices A and B for further details). Control of annual meadow grass is described as a reduction in ground cover compared to the untreated for each programme / treatment.

Approaches for the control of annual meadow grass have tended to historically include isoproturon (IPU), which can be considered to represent a ‘commercial standard’. Data in Table 3 indicates that IPU delivered, on average, a 95% reduction in the ground cover of annual meadow grass. Reductions achieved by other treatments in the experiment demonstrate that a range of other currently available herbicides are capable of delivering similar, or superior, levels of control across a wide range of application timings (ranging from pre-emergence through to a 2-3 leaf stage of the weed).

The highest, and most consistent, levels of control between studies tended to be associated with residual herbicides; the active ingredients flufenacet (e.g. Liberator and others), prosulfocarb (e.g. Defy) and pendimethalin (e.g. Stomp and others) being common to many of the better performing approaches.

Table 3. The effect of treatment on the ground cover of annual meadow grass, 2008 and 2009.

Treatment	Dose (l/ha)	Timing	Midlothian (2008) % ground cover 06-Jun	control %	Norfolk (2009) % ground cover 19 Feb	control %	Mean % control (common treatments)
Untreated	-	-	19.3	-	52.1	-	-
Untreated	-	-	21.4	-	43.8	-	-
isoproturon	1,000 g ai/ha	1-2 leaf	1.1	95	2.9	94	95
chlorotoluron	1,500 g ai/ha	1-2 leaf	0.8	96	0.1	100	98
Crystal	1.0 l/ha	Pre-em	0.2	99	4.1	91	95
Crystal	2.0 l/ha	Pre-em	0.0	100	0.0	100	100
Defy	1.5 l/ha	Pre-em	1.5	92	0.5	99	96
Defy	3.0 l/ha	Pre-em	0.3	99	0.1	100	100
Defy	3.0 l/ha	1-2 leaf	-	-	0.4	99	-
Liberator + Hurricane	0.15 l/ha + 0.03 l/ha	Pre-em	1.4	93	0.2	100	97
Liberator + Hurricane	0.3 l/ha + 0.06 l/ha	Pre-em	0.3	99	0.0	100	100
Flight	2.0 l/ha	Pre-em	0.4	98	1.8	96	97
Bacara	0.6 l/ha	Pre-em	2.4	88	2.6	95	92
Lexus	20 g/ha	Pre-em	7.9	61	37.5	22	42
Defy + Hurricane	1.5 l/ha + 0.12 l/ha	Pre-em	-	-	0.1	100	-
Hurricane	0.12 l/ha	Pre-em	2.9	86	8.1	83	85
Guillotine	0.05 l/ha	1-2 leaf	6.9	66	-	-	-
Guillotine	0.1 l/ha	1-2 leaf	1.4	93	1.7	97	95
flufenacet	120 g ai/ha	Pre-em	0.6	97	0.4	99	98
flufenacet	120 g ai/ha	1-2 leaf	-	-	0.1	100	-
pendimethalin	600 g ai/ha	Pre-em	2.2	89	2.1	96	93
pendimethalin + Lexus	600 g ai/ha + 20 g/ha	Pre-em	0.1	100	1.1	98	99
pendimethalin	1200 g ai/ha	Pre-em	0.3	99	0.7	99	99
Defy + Lexus	3.0 l/ha + 20 g/ha	Pre-em	0.3	98	0.6	99	99
Defy + Lexus	1.5 l/ha + 20 g/ha	Pre-em	0.8	96	-	-	-
Othello (+ Biopower)	0.5 l/ha	2-3 leaf	0.6	97	4.5	91	94
Othello (+ Biopower)	1.0 l/ha	2-3 leaf	0.5	98	-	-	-
Sig			P=<0.001		P=<0.001		
LSD			5.8		8.8		

3.3.2 Barren Brome – winter barley

Data from field experiments looking at the control of barren brome in winter barley from 2011 are presented as plant counts (Table 4) and head counts (Table 5) from three locations Norfolk, Edinburgh and Aberdeen (see Appendices A and B for further details). Brome at the Edinburgh and Aberdeen sites were natural populations while the Norfolk site was a sown population.

At the Norfolk site plant populations were low, with only around 1 plant m^{-2} recorded in untreated plots in February. At this point treatments targeted at the 2–3 leaf of the weed stage were not applied. However, of the applied treatments, with the exception of Graduate (flurtamone + diflufenican) and chlorotoluron, all treatments resulted in reduced plant populations compared to untreated plots. Despite the low plant populations brome head numbers were around 26 heads m^{-2}; this is unlikely to reflect late emergence with barren brome and may indicate that earlier plant counts underrepresented the populations. In general treatments including flufenacet (typically in Liberator) tended to give the higher levels of control with further improvements in this control apparent from 'stack' and 'sequence' approaches where additional flufenacet was included. A range of 'stack' and 'sequence' approaches resulted in excess of a 90% reduction in heads. Treatments where single applications of Graduate, chlorotoluron or Atlantis (iodosulfuron-methyl-sodium + mesosulfuron-methyl) were used did not result in any reduction in head numbers. It should be noted that Atlantis is not currently approved for use in barley and was included as an experimental treatment.

Plant counts at the Edinburgh and Aberdeen sites were carried out in March and April, slightly later than those at the Norfolk site. Populations were somewhat higher at these sites with 22 plants m^{-2} and 30 plants m^{-2} in untreated plots at Edinburgh and Aberdeen respectively. At both sites all treatments resulted in reductions in brome plant populations and, similar to the Norfolk site, treatments where Liberator (flufenacet + diflufenican) was used tended to be among the stronger treatments. At the Edinburgh site with regard to both plant and head number reductions 'stack' and 'sequence' approaches tended to deliver higher levels of control compared to the use of single actives ingredients or timings. Further, as noted at the Norfolk site, single treatments of Graduate and chlorotoluron resulted in inferior control of head numbers, particularly when compared to 'stack' and 'sequence' approaches. With regard to the Aberdeen site while numerical reductions in plant numbers were apparent across all treatments (*c.f.* untreated plots) differences were not significant. Control of brome heads was also typically lower than that seen on the other two sites, however, in general the higher levels of control again tended to be associated with the use of flufenacet particularly when used in combination with 'stack' and 'sequence' approaches.

The coded product HGCA1 is an as yet unapproved material currently under near market development. In all three studies, the material when used alone pre-emergence of the crop, resulted in useful levels of plant and head control, comparable to several other similarly timed treatments. In addition HGCA1 contributed to effective control of plants and heads when used in a range of ‘stack’ and ‘sequence’ approaches.

Table 4. The effect of treatment on barren brome plants in winter barley, 2011.

Treatment	**Dose (l/ha)**	**Timing**	**Norfolk** Plants m^{-2} 10/02/2011	**Norfolk** control %	**Edinburgh** Plants m^{-2} 14/04/2011	**Edinburgh** control %	**Aberdeen** Plants m^{-2} 22/03/2011	**Aberdeen** control %	**Mean control[b] %**
Untreated			0.9		22.2		29.9		
Liberator	0.6 l/ha	Pre-em	0.0	100	2.0	91	19.4	35	63
Avadex Excel	15 kg/ha	Pre-em	0.4	56	5.7	74	22.2	26	50
HGCA1	l/ha	Pre-em	0.4	56	3.7	83	15.7	47	65
HGCA1 [a]	l/ha	Pre-em	0.4	56	5.7	74	24.1	19	47
Liberator + HGCA1	0.6 l/ha + - l/ha	Pre-em	0.8	11	0.0	100	26.9	10	55
Firebird	0.3 l/ha	1-2 leaf	0.4	56	5.7	74	19.4	35	55
chlorotoluron	1500 g ai/ha	1-2 leaf	1.2	0	11.0	50	25.0	16	33
Graduate	0.625 l/ha	1-2 leaf	3.6	0	17.0	23	22.2	26	25
Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	0.0	100	0.0	100	19.4	35	68
Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em fb 1-2 leaf	0.0	100	2.0	91	16.7	44	68
Liberator fb chlorotoluron	0.6 l/ha fb 1500g	Pre-em fb 1-2 leaf	0.4	56	0.0	100	24.1	19	60
Liberator + HGCA1 fb chlorotoluron	0.6 l/ha + - l/ha fb 1500g	Pre-em fb 1-2 leaf	0.0	100	0.0	100	20.4	32	66
Atlantis WG (+ Biopower)	0.4 kg/ha	2-3 leaf	4.8	0	0.0	100	25.0	16	58
Liberator + HGCA1 fb Firebird	0.6 l/ha + - l/ha fb 0.3 l/ha	Pre-em fb 1 -2 leaf	0.0	100	0.0	100	29.6	1	51
Liberator+ HGCA1 fb Firebird + chlorotoluron	0.6 l/ha + - l/ha fb 0.3 l/ha + 1500g	Pre-em fb 1 -2 leaf	0.0	100	0.0	100	23.1	23	61
Sig			P = 0.0157		P = 0.0001		NS (P=0.55)		
LSD			0.6		9.9		13.9		

Note a. indicates that the material was lightly surface incorporated.

b. refers to the mean of Edinburgh and Aberdeen only due to low plant numbers on the Norfolk site.

fb = followed by

Table 5. The effect of treatment on barren brome heads in winter barley, 2011.

Treatment	Dose (l/ha)	Timing	Norfolk Heads m^{-2} 25/04/2011	Norfolk control %	Edinburgh Heads m^{-2} 30/05/2011	Edinburgh control %	Aberdeen Heads m^{-2} xx/05/2011	Aberdeen control %	Mean control %
Untreated			26.2		56.3		42.1		
Liberator	0.6 l/ha	Pre-em	2.0	92	8.0	86	21.9	48	75
Avadex Excel	15 kg/ha	Pre-em	13.0	50	13.0	77	37.0	12	46
HGCA1	l/ha	Pre-em	18.7	29	11.0	80	33.7	20	43
HGCA1 [a]	l/ha	Pre-em	15.0	43	20.0	64	42.1	0	36
Liberator + HGCA1	0.6 l/ha + - l/ha	Pre-em	1.7	94	0.3	99	16.8	60	84
Firebird	0.3 l/ha	1 -2 leaf	5.7	78	27.7	51	20.2	52	60
chlorotoluron	1500 g ai/ha	1-2 leaf	33.7	0	51.0	9	25.3	40	7
Graduate	0.625 l/ha	1-2 leaf	31.3	0	45.0	20	32.0	24	8
Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	0.0	100	3.3	94	20.2	52	82
Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em fb 1-2 leaf	0.0	100	4.0	93	11.8	72	88
Liberator fb chlorotoluron	0.6 l/ha fb 1500g	Pre-em fb 1-2 leaf	1.3	95	3.7	93	13.5	68	85
Liberator + HGCA1 fb chlorotoluron	0.6 l/ha + - l/ha fb 1500g	Pre-em fb 1-2 leaf	0.0	100	1.0	98	16.8	60	86
Atlantis WG (+ Biopower)	0.4 kg/ha	2-3 leaf	46.0	0	2.0	96	33.7	20	14
Liberator + HGCA1 fb Firebird	0.6 l/ha + - l/ha fb 0.3 l/ha	Pre-em fb 1 -2 leaf	0.0	100	2.0	96	20.2	52	83
Liberator+ HGCA1 fb Firebird + chlorotoluron	0.6 l/ha + - l/ha fb 0.3 l/ha + 1500g	Pre-em fb 1 -2 leaf	0.3	99	0.0	100	13.5	68	89
Sig			P = 0.0001		P = 0.0001		P = 0.01		
LSD			19.6		21.9		20.2		

Note a. indicates that the material was lightly surface incorporated.

3.3.3 Barren Brome – winter wheat

Experiments examining the control of barren brome in winter wheat were carried out in harvest years 2008, 2009, 2010 and 2011 at a range of locations; results are as set out in Table 6 (2008 and 2009), 7 (2010) and 8 (2011); see Appendices A and B for further details. With the exception of the Norfolk sites all other sites were natural populations; the Norfolk site was a sown population.

Results from sites at East Hermiston and East Lothian in 2008 and 2009 (respectively) are presented together in Table 6 and where treatments were common to both experiments mean data has been presented. The East Hermiston site had a high barren brome population with 53 plants m^{-2} over winter and 762 heads m^{-2} later in June in untreated plots. In general there was little reduction in plant numbers from any programme with the exception of isoproturon and chlorotoluron. Considering head numbers, although a number of approaches resulted in reductions in head numbers, the stronger and significant reductions tended to associated with the use of ALS inhibitor herbicides alone or within programmes. Treatments including iodosulfuron-methyl-sodium + mesosulfuron-methyl (in both Atlantis and Pacifica), the coded product HGCA2 (a product that was in near market development based on pyroxsulam) and tri-allate where associated with programmes giving the greatest levels of reduction in this experiment.

The East Lothian (2009) experiment had a much lower population with 27 heads m^{-2} in untreated plots. With the exception of the spring timing all treatments reduced brome head numbers compared to the untreated. The highest level of control was achieved by a Liberator (flufenacet + diflufenican) + Avadex Excel (tri-allate) and chlorotoluron 'sequence' (94% control) although the active ingredients prosulfocarb (Defy), flufenacet and tri-allate all provided useful control in selected treatments at low population levels.

Experiments undertaken in 2010 were carried out in Norfolk (814 heads m^{-2} in untreated plots) and at East Hermiston (10 heads m^{-2} in untreated plots). At the Norfolk site all autumn applied treatments reduced barren brome plant populations compared to untreated plots. While the degree of reduction was variable, several approaches reduced plant numbers to fewer than 2 plants m^{-2}; programmes involving the active ingredients flufenacet (e.g. in Liberator and Firebird), tri-allate (Avadex Excel) and chlorotoluron tended to feature in these approaches. Despite the high plant populations and head numbers, all treatments in this experiment reduced the number of barren brome heads (c.f. untreated plots). Two approaches resulted greater than 90% control of barren brome heads; specifically a pre-emergence Avadex Excel (tri-allate) with Liberator (flufenacet + diflufenican) followed by chlorotoluron approach (giving 94% control) and a pre- emergence Avadex Excel (tri-allate) with Liberator (flufenacet + diflufenican) followed by Atlantis (iodosulfuron-methyl-sodium + mesosulfuron-methyl) approach (giving 93% control); due to the high populations it should be noted that in both treatments in excess of 50 heads m^{-2} still remained. At these high weed levels, programmes involving flufenacet, tri-allate and chlorotoluron, generally with a suitable ALS inhibitor material, were tending to deliver the higher levels of control.

The East Hermiston (2010) site experienced a markedly lower barren brome pressure (10 heads m^{-2} in untreated plots). Within this scenario a number of treatments delivered in excess of a 95% reduction in head numbers (*cf*. untreated plots). Programmes involving the active ingredients flufenacet (e.g. in Liberator and Firebird), tri-allate (Avadex Excel) and chlorotoluron tended to feature in these approaches. Use of 'stack' and 'sequence' approaches again generally gave higher levels of head reduction. Many of the more effective programmes also involved the use of suitable ALS inhibitor materials within approaches.

Experiments undertaken in 2011 were again carried out in Norfolk and at East Hermiston. Pressure at the East Hermiston site was high with 189 barren brome plants m^{-2} in the early spring and 280 head m^{-2} in untreated plots. Differences in control of plant numbers were apparent across pre- and early post emergence treatments, with the higher levels of reduction typically being associated with materials containing flufenacet (e.g. Liberator). However the greatest reductions in barren brome plant numbers were associated with treatments using 'stacks' and 'sequences' of active ingredients. Several approaches reduced plant numbers to fewer than 10 plants m^{-2}. Frequently these programmes involved flufenacet, chlorotoluron and / or a suitable ALS inhibitor material. Within this experiment the reduction in barren brome head numbers closely followed that of the plant numbers. The lower barren brome pressure at the Norfolk site (8 plants m^{-2} and 57 heads m^{-2} in untreated plots) resulted in high levels of control; with a number of approaches delivering in excess of a 95% reduction in head numbers (*cf.* untreated plots). Use of 'stack' and 'sequence' approaches, frequently featuring flufenacet, chlorotoluron and / or a suitable ALS inhibitor material, were typically giving the higher levels of head reduction.

It should be noted that the herbicides Artist (flufenacet + metribuzin) and Skirmish (isoxaben + terbuthylazine) used within this series of barren brome experiments are not approved for use in cereals. The coded product HGCA1 is an as yet unapproved material currently under near market development. In all three studies, the material when used alone pre-emergence of the crop, resulted in useful levels of plant and head control, comparable to several other similarly timed treatments. In addition HGCA1 contributed to effective control of plants and heads when used in a range of 'stack' and 'sequence' approaches.

Table 6. The effect of treatment on barren brome plant and head numbers (in 2008) and head numbers (in 2009) in winter wheat.

Treatment	Dose (l/ha)	Timing	East Hermiston 2008 Plants m^{-2} 13/12/07	Heads m^{-2} 04/06/08	control %	East Lothian 2009 Heads m^{-2} 04/06/08	control %	Mean control %
Untreated			52.7	762.2		26.8		
Liberator fb Atlantis WG (+ Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	18.3	333.3	56			
Liberator fb Monitor	0.6 l/ha fb 25 g/ha	Pre-em fb spring	30.8	536.6	30	14.3	47	38
Crystal	4.0 l/ha	Pre-em	38.3	613.3	20	10.7	60	40
Defy	5 l/ha	Pre-em	32.5	770.0	0	3.3	88	44
Liberator	0.6 l/ha	Pre-em	51.6	796.6	0	7.3	73	36
Avadex Excel	15 kg/ha	Pre-em	48.3	913.3	0	10.0	63	31
Defy + Hurricane	5 + 0.12 l/ha	Pre-em	43.3	790.0	0	6.3	76	38
Hurricane	0.12 l/ha	Pre-em	67.5	693.3	9	12.7	53	31
Hurricane	0.25 l/ha	Pre-em	60.0	876.6	0			
flufenacet	240 g ai/ha	Pre-em	55.0	810.0	0	11.0	59	30
pendimethalin	1,200g ai/ha	Pre-em	50.0	853.3	0			
Liberator + Avadex Excel	0.6 l/ha fb 15 kg/ha	Pre-em				37	86	
Liberator fb chlorotoluron	0.6 l/ha fb 3,500 g ai/ha	Pre-em fb 1-2 leaf				5.7	79	
Avadex Excel + Liberator fb chlorotoluron	15 kg/ha + 0.6 l/ha fb 3,500 g ai/ha	Pre-em fb 1-2 leaf				1.7	94	
isoproturon	2,500 g ai/ha	1-2 leaf	18.3	720.0	6	18.3	32	19
chlorotoluron	3,500 g ai/ha	1-2 leaf	18.3	693.3	9	10.0	63	36
Atlantis WG (+ Biopower)	0.4 kg/ha	2-3 leaf	38.3	493.3	35			
Avadex Excel fb Atlantis WG (+ Biopower)	15 kg/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	29.1	230.0	70			
Atlantis WG (+ Biopower) + Hurricane	0.4 kg/ha+ 0.12 l/ha	2-3 leaf	47.5	323.3	58			
Othello (+ Biopower)	1.0 l/ha	2-3 leaf	59.1	670.0	12			
HGCA2 [a]	250 g/ha	2-3 leaf	55.8	670.0	12			
HGCA2 [a]	250 g/ha	Spring	40.8	266.6	65	26.7	1	33
Monitor	25 g/ha	Spring	37.5	646.6	15	19.0	29	22
Pacifica (+ BioPower)	0.5 kg/ha	Spring	70.8	220.0	71	37.0	0	36
Sig				P =<0.001		P=<0.001		
LSD				284.6		17.5		

Note a. appropriate adjuvants were used with this treatment

Table 7. The effect of treatment on barren brome plant numbers and head in winter wheat (2010).

Treatment	Dose (l/ha)	Timing	Norfolk Plants m^{-2} 25/01/2010	Norfolk Heads m^{-2} 24/06/2010	Norfolk control %	East Hermiston Heads m^{-2} 10/06/2010	East Hermiston control %	Mean control %
Untreated	-	-	79.6	814.0		9.8		
Liberator fb Atlantis WG (+ Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	4.9	216.0	73	0.3	97	85
Defy	5 l/ha	Pre-em	10.2	504.0	38	3.3	66	52
Liberator	0.6 l/ha	Pre-em	0.9	352.0	57	3.5	64	61
Avadex Excel	15 kg/ha = 2,250g ai	Pre-em	13.8	532.0	35	6.4	35	35
Defy + Liberator	5 l/ha + 0.6 l/ha	Pre-em	10.2	433.0	47	3.3	66	57
flufenacet	240 g ai/ha	Pre-em	14.2	356.0	56	7.3	26	41
Skirmish	1.0 l/ha	Pre-em	4.0	342.0	58	8.5	13	36
Artist	1.0 l/ha	Pre-em	2.7	289.0	64	4.0	59	62
chlorotoluron	2000 g ai/ha	1-2 leaf	58.2	620.0	24	11.7	0	12
Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	0.9	107.0	87	2.1	79	83
Liberator fb chlorotoluron	0.6 l/ha fb 2000 g ai/ha	Pre-em fb 1-2 leaf	1.3	121.0	85	3.4	65	75
Avadex Excel + Liberator fb chlorotoluron	15 kg/ha + 0.6 l/ha fb 2000 g ai/ha	Pre-em fb 1-2 leaf	0.0	51.0	94	0.5	95	94
Avadex Excel + Defy fb chlorotoluron	15 kg/ha + 5 l/ha fb 2000 g ai/ha	Pre-em fb 1-2 leaf	13.8	206.0	75	4.8	51	63
Atlantis WG (+ Biopower)	0.4 kg/ha	2-3 leaf	56.9	472.0	42	1.3	87	64
Atlantis WG (+ Biopower) + Hurricane	0.4 kg/ha+ 0.12 l/ha	2-3 leaf	48.0	552.0	32	4.2	57	45
Broadway Star	0.265 l/ha	2-3 leaf	48.9	491.0	40	0.4	96	68
Othello (+ Biopower)	1.0 l/ha	2-3 leaf	76.4	626.0	23	2.4	76	49
Avadex Excel fb Atlantis WG (+ Biopower)	15kg/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	4.4	275.0	66	1.2	88	77
Avadex Excel + Liberator fb Atlantis WG (+ Biopower)	15kg/ha + 0.6 l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	1.8	57.0	93	0.5	95	94
Liberator fb Broadway Star	0.6 l/ha fb 0.265 l/ha	Pre-em fb 2-3 leaf	8.0	243.0	70	0.0	100	85
Broadway Star	0.265 l/ha	Spring	44.9	588.0	28	1.8	82	55
Pacifica (+ BioPower)	0.5 kg/ha	Spring	100.0	457.0	44	2.8	71	58
Sig			P = 0.0001	P = 0.0001		P = 0.0001		
LSD			32.6	267.0		4.2		

Table 8. The effect of treatment on barren brome plant numbers and head in winter wheat (2011).

Treatment	Dose (l/ha)	Timing	Norfolk Plants m^{-2} 10/02/2011	Norfolk Heads m^{-2} 25/05/2011	Norfolk control %	East Hermiston Plants m^{-2} 14/04/2011	East Hermiston Heads m^{-2} 30/05/2011	East Hermiston control %	Mean control %
Untreated	-	-	7.7	57.2		188.7	280.1		
Liberator fb Atlantis WG (+ Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	0.0	1.0	98	0.0	4.0	99	98
Defy	5.0 l/ha	Pre-em	1.3	22.7	60	199.7	167.0	40	50
Defy	5.0 l/ha	1-2 leaf	0.7	12.7	78	189.0	177.3	37	57
Liberator	0.6 l/ha	Pre-em	0.7	12.0	79	18.3	87.0	69	74
HGCA1	- l/ha	Pre-em	2.0	24.0	58	173.7	170.0	39	49
Skirmish	1.0 l/ha	Pre-em	0.0	6.0	90	251.7	223.7	20	55
Artist	1.0 l/ha	Pre-em	1.3	4.3	92	18.3	62.7	78	85
chlorotoluron	2000 g ai/ha	1-2 leaf	2.3	23.0	60	133.3	137.7	51	55
chlorotoluron	1500 g ai/ha	1-2 leaf	1.3	27.7	52	196.0	204.0	27	39
Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	0.0	0.7	99	18.3	45.3	84	91
Liberator fb Firebird+ flufenacet	0.6 l/ha fb 0.3 l/ha+ 240 g ai/ha	Pre-em fb 1-2 leaf	0.0	9.0	84	11.0	40.7	85	85
Liberator + HGCA1	0.6 l/ha+ - l/ha	Pre-em	0.3	2.7	95	3.7	41.0	85	90
Liberator + HGCA1 fb chlorotoluron	0.6 l/ha+ - l/ha fb 1500g	Pre-em fb 1-2 leaf	0.0	1.3	98	3.7	16.7	94	96
Atlantis WG (+ Biopower)	0.4 kg/ha	2-3 leaf	15.3	34.7	39	3.7	17.3	94	67
Horus (+ Biopower)	1.2 l/ha	2-3 leaf	2.0	11.0	81	18.3	40.7	85	83
Broadway Star	0.265 l/ha	2-3 leaf	8.3	2.0	97	18.3	28.7	90	93
HGCA1 fb Atlantis WG (+ Biopower)	- l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	0.7	10.7	81	11.0	11.0	96	89
HGCA1 + Liberator fb Atlantis WG (+ Biopower)	- l/ha+ 0.6 l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf	0.0	0.0	100	7.3	4.0	99	99
Liberator fb Broadway Star	0.6 l/ha fb 0.265 l/ha	Pre-em fb 2-3 leaf	0.0	0.3	99	3.7	2.0	99	99
Broadway Star	0.265 l/ha	Spring	4.3	9.0	84	229.3	137.7	51	68
Pacifica (+ BioPower)	0.5 kg/ha	Spring	6.3	8.3	85	277.3	174.7	38	62
Sig			P = 0.0274	P=0.0001		P=0.0001	P=0.0001		
LSD			2.7	26.3		68.4	74.8		

3.3.4 Black-grass – winter oilseed rape

Experiments examining the control of black-grass in winter oilseed rape were carried out in harvest years 2009, 2010 and 2011 at a range of locations. Results are as set out in Tables 9 (2009), 10 (2010) and 11 (2011); see Appendices A and B for further details. All sites were natural populations in ‘farm crop’.

Experiments in 2009 were undertaken in Lincolnshire (Great Carlton and Orford) and Norfolk. Data are presented from March counts for the Lincolnshire sites and November counts for the Norfolk site. Winter kill (of crop and weeds) on the Norfolk site impacted on the integrity of later counts only data relating to pre-emergence treatments should be treated as viable. In addition to the individual site data, mean data from the two Lincolnshire sites is also presented in Table 9. Across all sites the use of metazachlor (Butisan S), napropamide (Devrinol T) and tri-allate (Avadex Excel) as pre-emergence treatments reduced black-grass populations compared to untreated controls. At all three sites where Butisan S was used at a higher dose (2.5 l ha^{-1} compared to 1.5 l ha^{-1}) the level of control increased; averaged across the two Lincolnshire sites this increased from a 39% to a 67% reduction on black-grass plant populations (however, it should be noted that this dose would no longer be permitted within current cumulative use restrictions for metazachlor). In general however, higher levels of control of black-grass plant populations were only achieved where carbetamide (Crawler) and/or propyzamide (Kerb Flo) were used. With regard to dose response, Kerb Flo demonstrated a slight tendency to higher levels of black-grass control at both Lincolnshire sites as dose was increased from 1.4 l ha^{-1} to 2.1 l ha^{-1}. Considering the timing of Kerb Flo at 2.1 l ha^{-1}, autumn timings of November and October gave greater control than a January timing. Autumn timings of Crawler resulted in comparable levels of control to Kerb Flo. With regard to sequences (applied in October followed by November) of either Kerb Flo (1.05 l ha^{-1}) followed by Kerb Flo (1.05 l ha^{-1}) or Crawler (1.75 kg ha^{-1}) followed by Kerb Flo (1.05 l ha^{-1}), at both Lincolnshire sites the latter approach outperformed the former; with an average improvement of 24% control achieved.

Field experimentation in 2010 was again undertaken in Lincolnshire. Data set out from this experiment in Table 10 indicates that a sole pre-emergence application of metazachlor (Butisan S) gave a 63% reduction in black-grass plant numbers with applications of napropamide (Devrinol T) and tri-allate (Avadex Excel) giving similar levels of control (50% and 65% respectively). A novel treatment looking at the pre-emergence use of carbetamide (Crawler) was also examined; this treatment is not approved, but the active ingredient has shown some suitability to earlier season use. While the level of control achieved with this approach was similar to that of the same dose of Crawler used in mid-November, crop damage was noted against the pre-emergence use. Pre-emergence dimethachlor was also assessed and resulted in similar levels of black-grass reduction to Butisan S; dimethachlor became available for use in oilseed rape in 2012 as Teridox (Syngenta). A range of experimental (non-approved) approaches were also examined through a series of applications at the 2 leaf stage of the oilseed rape crop, specifically: ethofumesate, flufenacet, isoxaben + terbuthylazine (Skirmish) and diquat (Reglone). With the exception of the diquat all treatments reduced black-grass populations compared to the untreated control, however, with the exception of the flufenacet all treatments resulted in crop damage. Of the approaches used only ethofumesate gave black-grass control comparable to a current standard of metazachlor (Butisan S) applied at the same time. In general higher levels of black-grass control were again associated with the use of carbetamide (Crawler) and/or propyzamide (Kerb Flo). In this experiment there was little difference in control with regard to dose; averaging for doses Kerb Flo resulted around 90% control and Crawler around 73% control of black-grass plants. With regard to the 'stacking' of pre-emergence herbicides for the control of black-grass plants, an Avadex Excel + Devrinol T + Centium programme gave control of 91%; similar to Kerb Flo in this study. However, the greatest black-grass plant reduction achieved in this experiment was associated with a Crawler (2.3 kg ha^{-1}) + Kerb Flo (1.4 l ha^{-1}) mix that delivered 96% control (although other Kerb Flo based approaches also achieved in excess of a 90% reduction on black-grass plants).

Data from experiments carried out in the 2011 harvest season along with mean data from both studies are presented in Table 11. As with earlier seasons both tri-allate (Avadex Excel) and metazachlor (Butisan S) resulted in similar reductions in black-grass plant numbers from single pre-emergence applications; although the level of control delivered through napropamide (Devrinol T) was lower. Carbetamide (Crawler) was also again evaluated pre-emergence as was propyzamide (Kerb Flo). Both products resulted in a lesser reduction in black-grass plant numbers compared to the use of either product at a November timing. While neither product is approved for use in this scenario the carbetamide gave better control than the propyzamide, but did result in crop damage. A wide range of stacks of pre-emergence herbicide options (that did not rely on propyzamide or carbetamide) were also evaluated in these studies; most approaches tended to give superior performance to the individual products used alone, however levels of control were still lower than the better performing approaches (typically involving carbetamide and/or propyzamide). Within these treatments the coded product HGCA1 was used. This is an as yet unapproved material currently under near market development. The experimental use of flufenacet (which is not approved for us in oilseed rape) was also examined further in 2011; the level of black-grass control achieved was comparable to (a current standard of) metazachlor (Butisan S) applied at the same time, but the overall level of control was low compared to other approached examined within the experiments. In both studies in 2011 the highest level of control tended to be associated with the use of propyzamide (Kerb Flo). This was particularly associated with the use of Kerb Flo at 2.1 l ha^{-1} or at lower doses when used in mixtures with carbetamide (Crawler).

Table 9. The effect of treatment on black-grass plant numbers in winter oilseed rape (2009).

Treatment	Dose (l/ha)	Timing	Lincs (Great Carlton) Plants m^{-2} 17/03/09	control %	Lincs (Orford) Plants m^{-2} 27/03/09	control %	Norfolk Plants m^{-2} 26/11/08	control %	Mean control %
Untreated	-	-	56.7		372.9		10.5		
Butisan S+ trifluralin fb Kerb Flo	1.5 l/ha+ 2.3 l/ha fb 2.1 l/ha	Pre-em fb Mid Nov	3.3	94	15.8	96	1.7	84	95
Butisan S	1.5 l/ha	Pre-em	40.7	28	185.8	50	8.0	24	39
Butisan S	2.5 l/ha	Pre-em	25.7	55	80.8	78	0.7	94	67
Centium	0.33 l/ha	Pre-em	31.0	45	466.7	0	4.7	56	23
Devrinol T	2.8 l/ha	Pre-em	19.7	65	130.0	65	2.3	78	65
Butisan S + Devrinol T	1.5 l/ha + 2.8 l/ha	Pre-em	13.3	76	68.3	82	4.0	62	79
Butisan S + Centium	1.5 l/ha + 0.33 l/ha	Pre-em	35.7	37	158.3	58	1.3	87	47
Avadex Excel	15 kg/ha	Pre-em	32.3	43	197.5	47	2.7	75	45
Butisan S fb Laser	1.5 l/ha fb 0.8 l/ha	Pre-em fb Mid Oct	32.7	42	113.3	70	0.0	100	56
Butisan S fb Kerb Flo	1.5 l/ha fb 1.7 l/ha	Pre-em fb Mid Nov	7.3	87	38.3	90	2.3	78	88
Kerb Flo	2.1 l/ha	Mid Oct	11.7	79	98.3	74	4.3	59	77
Kerb Flo	2.1 l/ha	Mid Nov	16.7	71	33.3	91	20.0	0	81
Kerb Flo	2.1 l/ha	Late Jan.	31.0	45	94.2	75	13.0	0	60
Kerb Flo	1.7 l/ha	Mid Nov.	19.3	66	50.8	86	12.7	0	76
Kerb Flo	1.4 l/ha	Mid Nov	21.3	62	70.0	81	14.7	0	72
Kerb Flo + Laser	1.7 l/ha + 0.8 l/ha	Mid Nov	7.0	88	68.3	82	9.0	14	85
Laser fb Kerb Flo	0.8 l/ha fb 1.7 l/ha	Mid Oct fb Mid Nov	9.7	83	50.0	87	5.3	49	85
Kerb Flo fb Kerb Flo	1.05 l/ha fb 1.05 l/ha	Mid Oct fb Mid Nov	24.7	56	181.7	51	13.0	0	54
Crawler	3.5 kg/ha	Mid Oct	14.7	74	11.7	97	9.3	11	85
Crawler	3.5 kg/ha	Mid Nov.	14.0	75	5.0	99	11.3	0	87
Crawler + Laser	3.5 kg/ha + 0.8 l/ha	Mid Nov	14.7	74	1.7	100	22.7	0	87
Crawler fb Kerb Flo	1.75 kg/ha fb 1.05 l/ha	Mid Oct fb Mid-Nov	19.3	66	38.3	90	6.3	40	78
Sig			P=<0.001		P=<0.001		P=<0.001		
LSD			13.3		101.3		9.6		

Notes

- Laser was always used in conjunction with an approved adjuvant.
- Mean % control is presented on Great Carlton and Orford sites only from March assessments.

Table 10. The effect of treatment on black-grass plant numbers and weed ground cover in winter oilseed rape (2010).

Treatment	Dose (l/ha)	Timing	Lincolnshire Plants m^{-2} 25/02/2010	control %
Untreated	-	-	45.70	
Butisan S fb Kerb Flo	1.5 l/ha fb 2.1 l/ha	Pre-em fb Mid Nov	2.30	95
Butisan S	1.5 l/ha	Pre-em	17.00	63
Devrinol T	2.8 l/ha	Pre-em	22.70	50
Avadex Excel	15 kg/ha	Pre-em	16.00	65
Crawler*	2.3 kg/ha	Pre-em	12.00	74
Teridox	2.0 l/ha	Pre-em	17.50	62
Kerb Flo	1.4 l/ha	Mid Nov	3.30	93
Kerb Flo	2.1 l/ha	Mid Nov	5.70	88
Crawler	2.3 kg/ha	Mid Nov	12.30	73
Crawler	3.5 kg/ha	Mid Nov	12.00	74
Kerb Flo + Crawler	1.4 l/ha + 2.3 kg/ha	Mid Nov	1.70	96
Kerb Flo + Crawler+ Laser	1.4 l/ha + 2.3 kg/ha + 0.8 l/ha	Mid Nov	2.30	95
Butisan S + Centium	1.5 l/ha + 0.33 l/ha	Pre-em	25.70	44
Butisan S+ Devrinol T	1.5 l/ha + 2.8 l/ha	Pre-em	16.00	65
Devrinol T + Centium	2.8 l/ha + 0.33 l/ha	Pre-em	13.70	70
Avadex Excel+ Devrinol T	15 kg/ha + 2.8 l/ha	Pre-em	10.30	77
Avadex Excel + Devrinol T + Centium	15 kg/ha + 2.8 l/ha + 0.33 l/ha	Pre-em	4.30	91
Butisan S	1.5 l/ha	2 leaf (crop)	13.00	72
flufenacet	240 g ai/ha	2 leaf (crop)	27.00	41
ethofumesate*	1000 g ai/ha	2 leaf (crop)	10.30	77
Skirmish*	1.0 l/ha	2 leaf (crop)	24.00	47
Reglone*	2.0 l/ha	2 leaf (crop)	67.70	0
Sig			P=<0.01	
LSD			31.8	

Notes

- Laser was always used in conjunction with an approved adjuvant.
- An * indicates that crop damage was noted (see section 3.3.4).

Table 11. The effect of treatment on black-grass plant numbers in winter oilseed rape (2011).

Treatment	Dose (l/ha)	Timing	Wiltshire Plants m^{-2} 10/03/2011	control %	Lincolnshire Plants m^{-2} 02/03/2011	control %	Mean control %
Untreated	-	-	398.1		93.4		
Butisan S fb Kerb Flo	1.5 l/ha fb 2.1 l/ha	Pre-em fb Mid Nov	18.1	95	3.7	96	96
Butisan S	1.5 l/ha	Pre-em	295.6	26	55.0	41	34
Devrinol T	2.8 l/ha	Pre-em	361.9	9	84.7	9	9
Avadex Excel	15 kg/ha	Pre-em	207.2	48	70.0	25	37
HGCA1	- l/ha	Pre-em			85.3	9	14
Crawler*	2.3 kg/ha	Pre-em	303.8	24	78.0	17	21
Kerb Flo	1.4 l/ha	Pre-em	330.6	17	72.0	23	20
Butisan S + HGCA1	1.5 l/ha + - l/ha	Pre-em			53.3	43	
Butisan S + Avadex Excel	1.5 l/ha + 15 kg/ha	Pre-em	171.3	57			
Crawler+ HGCA1	2.3 kg/ha + - l/ha	Pre-em			64.3	31	
Crawler+ Avadex Excel	2.3 kg/ha + 15 kg/ha	Pre-em	151.9	62			
Butisan S + Devrinol T	1.5 l/ha + 2.8 l/ha	Pre-em	248.1	38	66.0	29	34
Devrinol T + HGCA1	2.8 l/ha + - l/ha	Pre-em			53.0	43	
Devrinol T + Avadex Excel	2.8 l/ha + 15 kg/ha	Pre-em	199.4	50			
Devrinol T + HGCA1 (incorporated)	2.8 l/ha + - l/ha	Pre-em			65.7	30	
Devrinol T + Avadex Excel (incorporated)	2.8 l/ha + 15 kg/ha	Pre-em	168.8	58			
Butisan S + Devrinol T + HGCA1	1.5 l/ha+ 2.8 l/ha + - l/ha	Pre-em			64.3	31	
Butisan S + Devrinol T + Avadex Excel	1.5 l/ha + 2.8 l/ha + 15 kg/ha	Pre-em	130.0	67			
Butisan S + Devrinol T fb Kerb Flo	1.5 l/ha + 2.8 l/ha fb 1.4 l/ha	Pre-em fb Mid Nov	106.3	73	6.3	93	83
Kerb Flo	1.4 l/ha	Mid Nov	43.1	89	11.3	88	89
Kerb Flo	2.1 l/ha	Mid Nov	15.6	96	3.3	96	96
Crawler	2.3 kg/ha	Mid Nov	241.3	39	39.7	58	49
Crawler	3.5 kg/ha	Mid Nov	223.1	44	17.7	81	63
Kerb Flo + Crawler	1.4 l/ha + 2.3 kg/ha	Mid Nov	37.5	91	1.0	99	95
Butisan S	1.5 l/ha	2 leaf (crop)	391.9	2	59.0	37	20
flufenacet	240 g ai/ha	2 leaf (crop)	368.1	8	68.7	26	17
Sig			P=0.0001		P=0.0001		
LSD			92.2		28.0		

Note - An * indicates that crop damage was noted (see section 3.3.4).

3.3.5 Black-grass – winter barley

Experiments examining the control of black-grass in winter barley were carried out in harvest years 2008 (in Lincolnshire) and 2011 (Bedfordshire and Lincolnshire). Results are as set out in Tables 12 (2008) and 13 (2011) respectively; see Appendices A and B for further details. All sites were natural populations in 'farm crop'.

The Lincolnshire (2008) site had 30 plants m^{-2} and 108 heads m^{-2} in untreated plots. Where pre-emergence based herbicide was used alone those based around flufenacet tended to give the greater reductions on both plant and head numbers. Crystal (flufenacet + pendimethalin) gave higher levels of control than Liberator (flufenacet + diflufenican); although the difference in percentage control should be treated with some caution and considered in the context of other results presented in this section. Of the pre-emergence herbicide 'stacks' used those including flufenacet again tended to be give the greater reductions; typically delivering 70-80% reductions in black-grass head numbers. Although a prosulfocarb (Defy) + pendimethalin approach also resulted in similar levels of reduction in both black-grass plants (4 plants m^{-2}) and heads (24 heads m^{-2}, equating to a 78% reduction). Where herbicides were used in 'sequence' based approaches, compared to a designated commercial standard for 2008 (Liberator followed by isoproturon and pendimethalin (Stomp 400)) several other approaches resulted in similar or greater levels of reduction in both plant and head counts; typically delivering 80-90% reductions in black-grass head numbers. In particular the following approaches; Liberator followed by chlorotoluron and pendimethalin, Liberator followed by chlorotoluron and diflufenican and Liberator followed by pinoxaden (Axial) and pendimethalin.

Research in 2011 was undertaken at 2 sites; Bedfordshire 14 plants m^{-2} and 40 heads m^{-2} in untreated plots) and Norfolk (24 plants m^{-2} and 50 heads m^{-2} in untreated plots). As with data from 2008 where pre-emergence treatments were used alone, those involving flufenacet performed well, specifically, Crystal (flufenacet + pendimethalin) resulted in the greater reductions black-grass plants compared to Liberator (flufenacet + diflufenican) (although the difference to Liberator was not as marked as in 2008). Tri-allate (Avadex Excel) also resulted in reductions in black-grass plant numbers similar to those of flufenacet based products. Flupyrsulfuron-methyl (Lexus) used alone tended to deliver lower levels of control than flufenacet based approaches. Prosulfocarb (Defy) was examined alone in both a pre- and early post emergence slot; in both studies use of the product early post emergence improved control compare to pre-emergence (average black-grass plant numbers from pre-emergence treatment 14 plants m^{-2} and from application at the 1–2 leaf stage 7 plants m^{-2} based on a mean untreated population of 19 plants m^{-2}).

Of the herbicide ‘stacks’ and the ‘sequences’ of materials used pre- and early post emergence, those involving flufenacet at 240 g ai ha^{-1} or greater (e.g. approaches using Liberator or Crystal) were typically among the stronger approaches. Compared to a designated commercial standard for 2011 of Liberator (flufenacet + diflufenican) + Defy (prosulfocarb) followed by Axial (pinoxaden) and Stomp 400 (pendimethalin) several other approaches resulted in similar or greater levels of reduction in both plant and head counts; typically delivering mean reductions in black-grass head numbers of 85% or greater. While a range of combinations achieved this level of reduction the greatest mean reduction was associated with Liberator (flufenacet + diflufenican) + Defy (prosulfocarb) followed by Firebird (flufenacet + diflufenican); giving a mean reduction of 97% of black-grass heads.

Within the 2011 research examining approaches to black-grass control in winter barley, two non-approved materials were also examined; specifically Artist (flufenacet + metribuzin) which provided control similar to other flufenacet based pre-emergence options and a material coded as HGCA1. This, as yet unapproved material is currently under near market development. HGCA1 tended to perform less well than current standards when used alone pre-emergence of the crop, however, it did contribute effectively to control of black-grass plants and heads when used in a range of ‘stack’ and ‘sequence’ approaches.

Table 12. The effect of treatment on black-grass plant numbers in winter barley (2008).

Treatment	Dose (l/ha)	Timing	Lincolnshire Plants m^{-2} 02/01/2008	Heads m^{-2} 04/06/2008	control %
Untreated			30.2	108.2	0
Liberator fb isoproturon + Stomp 400	0.6 l/ha fb 2500 g/ha ai + 3.0 l/ha	Pre-em fb 1-2 leaf	3.7	22.7	79
Crystal	4.0 l/ha	Pre-em	2.0	12.0	89
Defy	5.0 l/ha	Pre-em	12.0	83.7	23
Liberator	0.6 l/ha	Pre-em	5.7	46.0	57
Lexus	20g/ha	Pre-em	28.7	73.7	32
Graduate	0.625 l/ha	Pre-em	14.3	83.7	23
Defy + pendimethalin	5.0 l/ha + 1200 g ai/ha	Pre-em	4.0	23.7	78
Defy + Lexus	5.0 l/ha + 20 g/ha	Pre-em	13.0	46.3	57
Crystal + Defy	4.0 + l/ha + 5.0 l/ha	Pre-em	3.0	28.0	74
Crystal + Lexus	4.0 l/ha + 20 g/ha	Pre-em	4.0	21.0	81
Crystal fb Liberator	4 l/ha fb 0.6 l/ha	Pre-em fb 1-2 leaf	4.0	23.7	78
Hurricane	0.12 l/ha	Pre-em	49.3	127.3	0
pendimethalin	1200 g ai/ha	Pre-em	19.3	57.0	47
Graduate	0.625 l/ha	1-2 leaf of crop	23.3	96.0	11
Crystal fb Graduate	4.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	4.7	34.3	68
chlorotoluron + Stomp 400	3500 g ai/ha + 3.0 l/ha	1-2 leaf	12.7	43.0	60
Liberator fb chlorotoluron + Stomp 400	0.6 l/ha fb 3500 g/ha ai + 3.0 l/ha	Pre-em fb 1-2 leaf	8.7	12.3	89
Crystal fb chlorotoluron + Hurricane	4.0 l/ha fb 3500 g/ha ai + 0.12 l/ha	Pre-em fb 1-2 leaf	3.3	8.0	93
Liberator fb Axial + Stomp 400	0.6 l/ha fb 0.45 l/ha + 3.0 l/ha	Pre-em fb 1-2 leaf	6.0	14.3	87
Sig				P= <0.001	
LSD				52.6	

Notes - Axial was always used in conjunction with an approved adjuvant.

Table 13. The effect of treatment on black-grass plant numbers in winter barley (2011).

Treatment	Dose (l/ha)	Timing	Bedfordshire Plants m^{-2} 15/03/2011	Bedfordshire Heads m^{-2} 25/06/2011	Bedfordshire control %	Lincolnshire Plants m^{-2} 02/03/2011	Lincolnshire Heads m^{-2} 30/06/2011	Lincolnshire control %	Mean Control %
Untreated			13.8	39.0		24.0	50.0		
Liberator + Defy fb Axial + Stomp 400	0.6 l/ha + 2.0 l/ha fb 0.45 l/ha + 3.0 l/ha	Pre-em fb 2-3 leaf	7.3	12.9	67	4.0	1.3	97	82
Defy	5.0 l/ha	Pre-em	17.8	38.1	2	11.0	14.7	71	37
Defy	5.0 l/ha	1-2 leaf	7.9	26.9	31	6.0	9.3	81	56
Liberator	0.6 l/ha	Pre-em	3.9	16.8	57	8.0	25.3	49	53
Crystal	4.0 l/ha	Pre-em	3.0	28.5	27	2.7	1.0	98	63
Artist	1.0 l/ha	Pre-em	6.3	13.3	66	7.0	6.0	88	77
Avadex Excel	15 kg/ha	Pre-em	4.8	9.3	76	5.3	15.7	69	73
HGCA1	- l/ha	Pre-em	10.1	14.3	63	19.0	36.7	26	45
Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em	2.6	4.9	87	5.3	1.0	98	93
Defy + HGCA1	5.0 l/ha + - l/ha	Pre-em	5.0	13.7	65	7.7	3.0	94	80
Lexus	20g/ha	Pre-em	6.3	10.6	73	12.0	52.0	0	37
chlorotoluron + Hurricane	1500g + 0.12 l/ha	1-2 leaf	13.1	38.7	1	9.7	12.3	75	38
Graduate	0.625 l/ha	1-2 leaf	17.5	47.6	0	22.3	28.3	43	22
Liberator fb chlorotoluron + Hurricane	0.6 l/ha fb 1500g + 0.12 l/ha	Pre-em fb 1-2 leaf	12.8	18.5	53	5.0	8.0	84	69
Defy + HGCA1 fb chlorotoluron + Hurricane	5.0 l/ha + - l/ha fb 1500g + 0.12 l/ha	Pre-em fb 1-2 leaf	2.5	9.2	76	7.0	3.3	93	85
Liberator + HGCA1 fb Firebird	0.6 l/ha + - l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	0.8	2.0	95	3.3	1.3	97	96
Liberator + Defy fb Firebird	0.6 l/ha + 5.0 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	0.8	2.4	94	2.3	0.0	100	97
Liberator + Defy fb Graduate	0.6 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	1.7	6.4	84	1.3	1.0	98	91
Defy + HGCA1 fb Firebird	5.0 l/ha + - l/ha fb 0.3 l/ha	Pre-em	1.6	9.2	76	3.7	3.7	93	85
Sig			P = 0.0001	P = 0.0001		P = 0.045	P = 0.0103		
LSD			8.2	18.9		15.1	33.1		

Note - Axial was always used in conjunction with an approved adjuvant.

3.3.6 Black-grass – winter wheat

Experiments examining the control of black-grass in winter wheat were carried out in harvest years 2008 (Table 14), 2009 (Table 15), 2010 (Table 16) and 2011 (Table 17); see Appendices A and B for further details. All sites were natural populations in 'farm crop'. Impacts of resistance to herbicides on field performance were apparent in some experiments and are highlighted in the text where relevant.

Data from experiments in 2008 undertaken in Wiltshire, Lincolnshire and Suffolk are presented in Table 14. Studies provided a range of intensities of black-grass; specifically 53 (Suffolk), 204 (Lincolnshire) and 345 (Wiltshire) heads m^{-2} in untreated plots. A typical farm programme for 2008 of Crystal (flufenacet + pendimethalin) plus trifluralin followed by Atlantis (Iodosulfuron-methyl-sodium + mesosulfuron-methyl) resulted in 99–100% reduction in black-grass heads at all sites. The performance of other approaches varied in relation to black-grass pressure. At the lower pressure site, Suffolk (2008), of the pre-emergence approaches used, those based around flufenacet tended to deliver the greatest reductions in final head numbers. Comparing the performance of Crystal and Liberator (flufenacet + diflufenican) with flufenacet alone (at the same dose of active ingredient; 240 g ai/ha) the flufenacet resulted in similar reductions in final head numbers. There was little reduction in final head numbers where both diflufenican (Hurricane) and pendimethalin were used at the doses of active ingredient corresponding to those contained in Crystal and Liberator; however where these materials were used at higher doses marked improvements in control were noted. The control of black-grass heads resulting from the use of prosulfocarb (Defy) alone as a pre-emergence treatment was improved either through the addition of a further active ingredient (in this case pendimethalin at the same dose contained in Crystal) or when the Defy was used alone at the peri-emergence stage. Within this study, under a low black-grass pressure, (excluding the Atlantis WG based approach) a range of 'stacking' and 'sequencing' approaches delivered 90–100% control of black-grass heads; with 3 programmes delivering 100% control. Typically the stronger performing programmes involved flufenacet (including a Liberator and Crystal 'sequence' delivering 480 g ai/ha of flufenacet), although Defy was also common to several approaches.

The Lincolnshire (2008) study had a higher black-grass pressure in untreated plots with 204 heads m^{-2}. While trends in performance were similar to those described for the Suffolk (2008) site, in general, the level of reduction of heads tended to be less marked. Specifically, where pre-emergence materials were used alone, those involving flufenacet were the stronger performing, but again flufenacet used alone (at the same active ingredient dose as Crystal and Liberator) resulted in similar levels of control (while diflufenican and pendimethalin used at the relevant doses did not). Similarly the control of black-grass heads delivered through prosulfocarb (Defy) was improved where the material was used in conjunction with pendimethalin or used alone at a peri-emergence stage. 'Stacking' and ‘sequencing’ approaches tended to deliver some of the greater reductions in head numbers in the experiment; but the level of reduction was typically only 60-75%. Again flufenacet and prosulfocarb were common to the more effective approaches. The ‘farm standard’ programme involving Atlantis WG resulted in a 99% reduction in head numbers. With regard to the Wiltshire (2008) experiment, black-grass pressure was very high (345 heads m^{-2}) and other than the farm standard programme treatment (involving Atlantis) none of the other approaches resulted in control of black-grass heads exceeding a 50% reduction; this reduction was achieved by a Liberator and Crystal ‘sequence’ delivering 480 g ai/ha of flufenacet.

Data from experiments in Wiltshire (88 heads m^{-2} in untreated plots), Lincolnshire (222 heads m^{-2} in untreated plots) in 2009 are presented in Table 15. A typical farm programme for 2009 of Crystal (flufenacet + pendimethalin) plus trifluralin followed by Atlantis (iodosulfuron-methyl-sodium + mesosulfuron-methyl) resulted in excess of 95% reduction in black-grass heads at both sites. As with 2008 data the performance of other approaches varied in response to black-grass pressure. In Wiltshire (2009) where pre-emergence options were used alone the reduction in final head numbers was typically 50-60%. However, three programmes delivered in excess of 95% control; Crystal + Defy (prosulfocarb) followed by Graduate (flurtamone + diflufenican) followed by Guillotine (flumioxazine),, Liberator (flufenacet + diflufenican) + Defy and Liberator followed by Crystal (flufenacet + pendimethalin) approaches resulted in 99%, 97% and 96% reductions in black-grass heads respectively. A range of other ‘stack’ and ‘sequence’ approaches also gave around 90% control of black-grass heads; flufenacet was common to all these approaches. The Lincolnshire (2009) site had untreated populations of 222 heads m^{-2}. Where pre-emergence herbicides were used alone the active ingredient flufenacet was common to the treatments giving the greatest reductions in black-grass plant numbers m^{-2}; the translation of this into reductions in head numbers was less apparent probably due to compensatory re-growth. The greatest reductions in both black-grass plant and head numbers were associated with ‘stack’ or ‘sequence’ approaches; again flufenacet was common to the approaches giving the greatest reductions. For example, Liberator followed by Crystal (either with or without additional pendimethalin) resulted in a 90–94% reduction in black-grass head numbers, while a range of approaches based around Liberator + Defy in combination with additional active ingredients such as flumioxazine (Guillotine) and flurtamone + diflufenican (Graduate) also resulted in similar reductions. However, due to the high population, even a reduction of around 95% would result in around 10 black-grass heads m^{-2} remaining.

Experiments carried out in very high black-grass pressure sites 2010 in Bedfordshire and Lincolnshire (782 heads m^{-2} and 1832 heads m^{-2} respectively in untreated plots) were undertaken with very dry autumn conditions; data are presented in Table 16. On the Lincolnshire (2010) site a typical farm programme of Liberator (flufenacet + diflufenican) plus Defy (prosulfocarb) followed by Atlantis (iodosulfuron-methyl-sodium + mesosulfuron-methyl) gave only very limited control of black-grass plants and heads (a 33% reduction in head numbers). Pot tests of the black-grass seed (undertaken at Rothamsted Research) indicated resistance to Atlantis (demonstrated through tests examining vigour and foliage weight). Of all the programmes examined in 'stack' and 'sequence' approaches only 2 reduced plant numbers to fewer than 10 plants m^{-2}; specifically Defy + tri-allate (Avadex Excel) followed by chlorotoluron and Hurricane (diflufenican) and Defy + Avadex Excel followed by flurtamone + diflufenican (Graduate) which reduced plant populations to 6 and 9 plants m^{-2} respectively. The former of these programmes resulted in a 92% reduction in black-grass heads; leaving 59 heads m^{-2}.

The Bedfordshire (2010) experiment also demonstrated only limited control from the typical farm programme (with pot tests also suggesting some level of resistance to Atlantis). Due to high populations percentage ground cover was used to assess black-grass plant populations on this site. Considering pre-emergence herbicides used alone the greatest reductions were associated with tri-allate (Avadex Excel) and a range of approaches involving this active ingredient were among the stronger programmes. Although a Liberator followed by Defy + Graduate approach also resulted in similar reductions. Typical final reductions in black-grass head numbers on this site were 20–30% from the stronger programmes.

Within the experiments carried out in 2009 and 2010 two products not approved for the control of black-grass in winter wheat were also examined, specifically Artist (flufenacet + metribuzin) and Skirmish (isoxaben + terbuthylazine); neither herbicide resulted improved control compared to current alternatives or any appreciable crop damage.

Data from 2011, presented in Table 17, details experiments undertaken in Hampshire (247 heads m^{-2} in untreated plots) and Lincolnshire (106 heads m^{-2} in untreated plots). On both sites a typical farm programme of Liberator (flufenacet + diflufenican) plus Defy (prosulfocarb) followed by Atlantis (iodosulfuron-methyl-sodium + mesosulfuron-methyl) resulted in excess of a 95% reduction in black-grass heads compared to untreated plots. Considering the Lincolnshire (2011) site where pre-emergence products were used alone products based on flufenacet (e.g. Liberator and Crystal) and tri-allate (Avadex Excel) gave the greater reductions although, as with previous seasons, a pre-emergence 'stack' for Liberator and Defy (prosulfocarb) was also effective. In addition to adding Defy to the 'stack' similar improvements were also delivered through addition of further flufenacet based materials such as Liberator followed by Firebird (flufenacet + diflufenican). A limited range of early post emergence options were also considered. Within these approaches chlorotoluron was evaluated at 1500 g ai ha^{-1} and at 2000 g ai ha^{-1}, with the higher dose giving some improvement in black-grass control, however the use of flurtamone + diflufenican (Graduate) at this timing was more effective than either dose of chlorotoluron. In general the higher levels of control of both black-grass plant and head numbers were associated with 'stack' and 'sequence' approaches; herbicides based around flufenacet and prosulfocarb were common to many of these approaches. Results from the Hampshire site were similar to those from Lincolnshire with a pre-emergence 'stack' of Liberator + Defy and approaches using higher cumulative doses of flufenacet giving good reductions in black-grass plant and head numbers; specifically, from a base of 247 heads m^{-2} in untreated plots, Liberator + Defy reduced this to 0.3 heads m^{-2} and Liberator followed by Firebird to 1.8 heads m^{-2}. A range of other 'stack' and 'sequence' approaches also delivered in excess of 95% control of black-grass heads; typically flufenacet and/or prosulfocarb were common to these approaches although a range of other active ingredients including chlorotoluron, flurtamone and diflufenican were used in specific approaches. Within the 2011 research examining approaches to black-grass control in winter wheat, the non-approved herbicide coded as HGCA1 was also examined; this material is currently under near market development. HGCA1 tended to perform less well than current standards when used alone pre-emergence of the crop, however, did contribute effectively to control of black-grass plants and heads when used in a range of 'stack' and 'sequence' approaches.

Table 14. The effect of treatment on black-grass plant numbers in winter wheat (2008).

Treatment	Dose (l/ha)	Timing	Lincolnshire Heads m^{-2} 16/06/08	Lincolnshire control %	Wiltshire Plants m^{-2} 06/12/07	Wiltshire Heads m^{-2} 27/05/08	Wiltshire control %	Suffolk Plants m^{-2} 20/12/07	Suffolk Heads m^{-2} 27/05/09	Suffolk control %	Mean %
Untreated			204.1	0	120.7	344.6	0	2.2	53.0	0	
Crystal + trifluralin fb Atlantis	4.0 l/ha + 2.3 l/ha fb 0.4kg/ha	Pre-em fb 2-3 leaf[W]	1.6	99	25.6	3.3	99	0.7	0.0	100	99
Crystal	4.0 l/ha	Pre-em	124.2	39	80.0	265.8	23	0.7	13.7	74	45
Defy	5.0 l/ha	Pre-em	225.8	0	86.3	279.2	19	0.7	42.7	20	13
Liberator	0.6 l/ha	Pre-em	75.8	63	75.6	293.3	15	0.3	6.0	89	56
Graduate	0.625 l/ha	Pre-em	228.3	0	93.8	325.8	5	1.7	32.3	39	15
Guillotine	0.1 l/ha	1-2 leaf	306.7	0	86.3	251.7	27	1.7	24.0	55	27
Defy + pendimethalin	5.0 l/ha + 1200 g ai/ha	Pre-em	90.8	56	94.4	351.7	0	0.7	15.3	71	42
Crystal + Defy	4.0 l/ha + 5.0 l/ha	Pre-em	52.5	74	54.4	260.0	25	0.7	4.3	92	64
flufenacet	240 g ai/ha	Pre-em	80.0	61	61.9	248.3	28	0.7	14.0	74	54
Hurricane	0.12 l/ha	Pre-em	183.3	10	117.5	379.2	0	3.7	56.3	0	3
Hurricane	0.25 l/ha	Pre-em	209.2	0	150.0	405.0	0	1.3	23.3	56	19
pendimethalin	1200 g ai/ha	Pre-em	170.8	16	95.6	296.7	14	1.3	48.0	9	13
pendimethalin	1980 g ai/ha	Pre-em	107.5	47	74.4	290.0	16	0.7	24.3	54	39
Crystal	4.0 l/ha	Peri-em	165.8	19	68.3	235.8	32	0.0	3.3	94	48
Defy	5.0 l/ha	Peri-em	94.2	54	66.9	281.7	18	1.3	15.0	72	48
Graduate	0.625 l/ha	1-2 leaf	247.5	0	70.0	264.2	23	2.0	37.7	29	17
Liberator fb Crystal	0.6 l/ha fb 4 l/ha	Pre-em fb peri-em	80.3	60	43.1	174.2	50	0.3	0.0	100	70
Crystal fb Defy	4.0 l/ha fb 5.0 l/ha	Pre-em fb peri-em	49.2	76	70.0	336.7	2	1.0	5.3	90	56
Defy fb Crystal	5.0 l/ha fb 4.0 l/ha	Pre-em fb peri-em	75.8	63	79.4	251.7	27	0.3	6.0	89	60
Crystal fb Graduate	4.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	73.3	64	75.0	246.7	28	0.3	8.0	85	59
Crystal+ Defy fb Graduate	4.0 l/ha+ 5.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	80.0	61	62.5	297.5	14	0.0	0.0	100	58
Crystal fb Defy fb Graduate	4.0 l/ha fb 5.0 l/ha fb 0.625 l/ha	Pre-em fb peri-em fb 1-2 leaf	52.4	74	79.4	297.5	14	0.3	0.0	100	63
Sig			P=<0.001			P=<0.001			P=<0.001		
LSD			120.0			120.3			18.7		

Note - Atlantis was always used in conjunction with the approved adjuvant.
W refers to growth stage of weed not crop.

Table 15. The effect of treatment on black-grass plant numbers in winter wheat (2009).

Treatment	Dose (l/ha)	Timing	Lincolnshire Plants m^{-2} 18.02.09	Lincolnshire Heads m^{-2} 19.06.09	control %	Wiltshire Heads m^{-2} 18.06.09	control %	Mean control %
Untreated			12.7	222.1		78.1		
Crystal + trifluralin fb Atlantis	4.0 l/ha + 2.3 l/ha fb 0.4kg/ha	Pre-em fb 2-3 leaf[W]	0.3	8.7	96	0.0	100	98
Crystal	4.0 l/ha	Pre-em	0.7	47.7	79	27.5	65	72
Defy	5.0 l/ha	Pre-em	2.3	111.7	50	37.0	53	51
Liberator	0.6 l/ha	Pre-em	0.7	124.0	44	30.0	62	53
Crystal + Defy	4.0 l/ha + 5.0 l/ha	Pre-em	1.3	28.7	87	31.0	60	74
Defy + Hurricane	5.0 l/ha + 0.12 l/ha	Pre-em	4.0	61.7	72	25.3	68	70
Liberator + Hurricane	0.6 l/ha + 0.12 l/ha	Pre-em	0.7	69.3	69	36.8	53	61
Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em	0.3	56.3	75	2.8	97	86
flufenacet	240 g ai/ha	Pre-em	2.0	77.7	65	49.8	36	51
Hurricane	0.25 l/ha	Pre-em	4.3	152.0	32	22.0	72	52
pendimethalin	1200 g ai/ha	Pre-em	3.3	102.0	54	24.5	69	61
Skirmish	1.0 l/ha	Pre-em	7.0	119.7	46	26.5	66	56
Artist	1.0 kg/ha	Pre-em	7.0	303.7	0	65.5	16	8
Crystal	4.0 l/ha	Peri-em	1.0	52.7	76	27.0	65	71
Defy	5.0 l/ha	Peri-em	4.3	98.3	56	35.0	55	55
Graduate	0.625 l/ha	1-2 leaf	7.0	162.3	27	48.0	39	33
chlorotoluron + Hurricane	3500g + 0.12 l/ha	1-2 leaf	6.3	122.3	45	25.8	67	56
Guillotine	0.1 l/ha	1-2 leaf	4.3	214.7	3	35.3	55	29
Liberator fb Crystal	0.6 l/ha fb 4 l/ha	Pre-em fb peri-em	0.0	23.0	90	3.5	96	93
Liberator fb Crystal + pendimethalin	0.6 l/ha fb 2.0 l/ha + 1.8 l/ha	Pre-em fb peri-em	0.3	13.3	94	8.8	89	91
Crystal fb Defy	4.0 l/ha fb 5.0 l/ha	Pre-em fb peri-em	0.0	30.3	86	7.8	90	88
Crystal fb Graduate	4.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	0.3	14.0	94	19.5	75	84
Crystal + Defy fb Graduate	4.0 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	0.7	15.3	93	9.0	89	91
Crystal + Defy fb Graduate fb Guillotine	4.0 l/ha + 5.0 l/ha fb 0.625 l/ha fb 0.1 l/ha	Pre-em fb 1-2 leaf fb 2-3 leaf	0.7	20.0	91	0.8	99	95
Sig			P=<0.001	P=<0.001		P=<0.001		
LSD			1.0	73.0		36.6		

Note - Atlantis was always used in conjunction with the approved adjuvant.
W refers to growth stage of weed not crop.

Table 16. The effect of treatment on black-grass plant numbers in winter wheat (2010).

Treatment	Dose (l/ha)	Timing	Bedfordshire Cover (%)* 09/12/2009	Bedfordshire Heads m^{-2} 03/06/2010	Bedfordshire Control %	Lincolnshire Plants m^{-2} 26/10/2010	Lincolnshire Heads m^{-2} 15/06/2010	Lincolnshire Control %	Mean Control %
Untreated			37.8	1831.7		236.6	782.1		
Liberator + Defy fb Atlantis	0.6 l/ha + 2.0 l/ha fb 0.4kg/ha	Pre-em fb 2-3 leaf[W]	14.4	1188.3	35	93.9	524.5	33	34
Defy	5.0 l/ha	Pre-em	21.5	1326.7	28	131.3	566.7	28	28
Liberator	0.6 l/ha	Pre-em	35.8	1728.3	6	889.3	730.0	7	7
Crystal	4.0 l/ha	Pre-em	26.9	1687.5	8	59.0	372.5	52	30
flufenacet	240 g ai/ha	Pre-em	25.8	1270.0	31	156.3	807.5	0	16
Skirmish	1.0 l/ha	Pre-em	17.5	1409.2	23	161.0	629.2	20	22
Artist	1.0 kg/ha	Pre-em	18.5	1565.8	15	138.7	600	23	19
Avadex Excel	15 kg/ha	Pre-em	10.3	1605.0	12	75.7	436.7	44	28
Defy + Hurricane	5.0 l/ha + 0.12 l/ha	Pre-em	16.4	1634.2	11	69.3	444.2	43	27
Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em	27.3	1345.0	27	55.3	425.8	46	37
Defy + Avadex Excel	5.0 l/ha + 15 kg/ha	Pre-em	13.3	1502.5	18	39.7	259.2	67	43
chlorotoluron + Hurricane	2000g + 0.12 l/ha	Pre-em	43.8	1675.8	9	180.7	685	12	11
Reglone	2.0 l/ha	Peri-em	15.6	1439.2	21	196.3	730.8	7	14
chlorotoluron + Hurricane	2000g + 0.12 l/ha	Peri-em	32.5	1614.2	12	188.0	719.2	8	10
Topik	0.25 l/ha	1-2 leaf	42.5	1751.7	4	157.7	816.7	0	2
chlorotoluron + Hurricane	2000g + 0.12 l/ha	1-2 leaf	20.2	1450.8	21	166.7	593.3	24	23
Graduate	0.625 l/ha	1-2 leaf	46.7	1635.8	11	145.3	754.2	4	8
Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	43.0	1606.7	12	67.3	563.3	28	20
Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em fb 1-2 leaf	16.7	1505.8	18	84.0	465	41	30
Liberator fb Firebird + chlorotoluron	0.6 l/ha fb 0.3 l/ha + 2000g	Pre-em fb 1-2 leaf	29.3	1210.0	34	49.3	233.3	70	52
Liberator fb chlorotoluron + Hurricane	0.6 l/ha fb 2000g + 0.12 l/ha	Pre-em fb 1-2 leaf	38.2	1619.2	12	77.7	530.8	32	22
Defy + Avadex Excel fb chlorotoluron + Hurricane	5.0 l/ha + 15 kg/ha fb 2000g + 0.12 l/ha	Pre-em fb 1-2 leaf	14.4	1361.7	26	5.7	59.2	92	59
Defy + Avadex Excel fb Graduate	5.0 l/ha + 15 kg/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	11.1	1332.5	27	9.0	151.7	81	54
Liberator fb Defy + Graduate	0.6 l/ha + 5.0 l/ha 0.625 l/ha	Pre-em fb 1-2 leaf	10.6	1385.0	24	36.0	269.2	66	45
Sig			P = 0.075	P = 0.114		P = 0.0001	P = 0.0001		
LSD			25.9	434.9		59.1	128.0		

Notes Atlantis was always used in conjunction with the approved adjuvant.
W refers to growth stage of weed not crop.
* - Black-grass plants in Bedfordshire assessed as percentage ground cover.

Table 17. The effect of treatment on black-grass plant numbers in winter wheat (2011).

Treatment	Dose (l/ha)	Timing	Lincolnshire Plants m^{-2} 02/03/2011	Lincolnshire Heads m^{-2} 30/06/2011	control %	Hampshire Plants m^{-2} 14/12/2010	Hampshire Heads m^{-2} 16/05/2011	control %	Mean control %
Untreated			49.5	106.0		21.8	246.7		
Liberator + Defy fb Atlantis	0.6 l/ha + 2.0 l/ha fb 0.4kg/ha	Pre-em fb 2-3 leaf[w]	12.7	4.7	96	2.0	0.0	100	98
Defy	5.0 l/ha	Pre-em	41.0	74.7	30	6.5	77.8	68	49
Liberator	0.6 l/ha	Pre-em	15.0	38.0	64	6.0	83.5	66	65
Crystal	4.0 l/ha	Pre-em	3.7	13.0	88	2.8	12.8	95	91
flufenacet	240 g ai/ha	Pre-em	21.3	45.3	57	2.5	24.5	90	74
Avadex Excel	15 kg/ha	Pre-em	11.0	27.7	74	6.0	88.0	64	69
HGCA1	- l/ha	Pre-em	20.7	39.0	63	5.0	129.0	48	55
Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em	8.3	18.3	83	0.5	0.3	100	92
Defy + HGCA1	5.0 l/ha + - l/ha	Pre-em	14.7	18.0	83	9.3	109.8	55	69
chlorotoluron	2000g	1-2 leaf	53.7	80.7	24	10.5	107.0	57	40
chlorotoluron	1500g	1-2 leaf	57.7	100.3	5	21.8	163.8	34	19
Topik	0.25 l/ha	1-2 leaf	65.0	89.7	15	15.5	187.8	24	20
Graduate	0.625 l/ha	1-2 leaf	18.0	56.0	47	23.5	159.8	35	41
Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em fb 1-2 leaf	13.3	18.0	83	2.8	1.8	99	91
Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em fb 1-2 leaf	7.0	11.7	89	2.3	0.0	100	94
Liberator fb Firebird + chlorotoluron	0.6 l/ha fb 0.3 l/ha + 1500g	Pre-em fb 1-2 leaf	6.3	16.3	85	0.8	0.0	100	92
Defy + HGCA1 fb chlorotoluron + Hurricane	5.0 l/ha + - l/ha fb 1500g + 0.12 l/ha	Pre-em fb 1-2 leaf	5.7	10.7	90	6.5	12.5	95	92
Defy + HGCA1 fb Firebird	5.0 l/ha + - l/ha fb 0.3 l/ha	Pre-em	3.3	8.3	92	3.3	16.8	93	93
Defy + HGCA1 fb Liberator	5.0 l/ha + - l/ha fb 0.6 l/ha	Pre-em	6.0	3.3	97	1.8	2.8	99	98
Defy + HGCA1 fb Graduate	5.0 l/ha + - l/ha fb 0.625 l/ha	Pre-em	10.7	25.0	76	3.8	27.3	89	83
Liberator + Defy fb Graduate	0.6 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em fb 1-2 leaf	7.7	21.3	80	2.8	0.0	100	90
Sig			P = 0.0001	P = 0.0001		P = 0.0001	P = 0.0001		
LSD			36.1	36.1		12.8	78.7		

Note - Atlantis was always used in conjunction with the approved adjuvant.
W refers to growth stage of weed not crop.

3.4 Discussion

3.4.1 Annual Meadow Grass

A range of approaches have the potential to replace the role of isoproturon (IPU) in providing effective control of annual meadow grass. Many of these approaches will require a modification to timing compared to IPU, however they do demonstrate dose flexibility and, in addition to controlling annual meadow grass, many are also capable of delivering useful control of a range of broad-leaved weeds.

The range of herbicide options available can also provide control opportunities over a range of timings. While the product label and other relevant manufacturer information should always be consulted prior to use for specific guidance on approvals, timings and weed spectra the, results from this research would suggest the following -

- Pre-emergence: results demonstrate that a range of options based around residual herbicides can provide high levels of control. Programmes including (but not limited to) the active ingredients flufenacet, prosulfocarb and pendimethalin have tended to be among the stronger performing approaches and can also deliver useful control of a range of other weeds. These active ingredients can demonstrate useful dose flexibility providing a range of cost options to growers. Many of these materials are also suited to peri- or early post emergence use.
- Post emergence: while the 2–3 leaf of the crop stage has been a more traditional time to control annual meadow grass, options at this timing have become more limited. However, active ingredients such as chlorotoluron (subject to varietal suitability) and flumioxazine can still deliver useful levels of control. For later post emergence control ALS inhibitor-based products such as diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl (Othello) can also provide effective control and will also provide useful control of other weeds.

While research addressing the management of annual meadow grass was only undertaken in winter wheat, where products are approved, it could be expected that control in winter barley should be comparable. However, it should be noted that greater crop competition in barley can augment control and that some herbicides used for annual meadow grass management in wheat e.g. diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl (Othello) are not approved for use in barley.

3.4.2 Barren Brome – winter barley

Across a range of treatments for the control of barren brome in winter barley ‘stack’ and ‘sequence’ approaches tended to deliver higher levels of control compared to the use of single actives ingredients or timings; even at low populations.

Comparing the percentage control of brome heads from the treatments used at the Edinburgh and Aberdeen sites against the spring plant numbers suggests that higher brome plant populations tended to result in poorer control of brome heads in winter barley. In addition findings suggest that only where brome populations of (approximately) 10–15 plants m^{-2} (or fewer) were present in the spring could control in excess of 80% be achieved; this is illustrated in Figure 1. This is perhaps not unexpected given that the herbicides available for brome control in winter barley are ostensibly residual herbicides and autumn activity during the emergence window of barren brome will be important. In the spring in barley (more so than in winter wheat) crop competition is also likely to be important. Where brome populations are high non-chemical management practices should also be considered.

The active ingredient flufenacet was common to many of the more effective barren brome control programmes and reduction in heads can be seen in response to increased dose. On two of the three sites the greatest response was incurred from increasing the flufenacet dose from 240 g ai /ha to 360 g ai /ha with a much smaller response going to 480 g ai/ha; a summary of this is presented in Figure 2. Tri-allate (Avadex Excel) also gave useful levels of control of barren brome, although typically less than that delivered by flufenacet based approaches. The potential value of tri-allate in ‘stack’ and ‘sequence’ approaches should also be considered.

Where flurtamone + diflufenican (Graduate) and chlorotoluron were used alone initial reductions in the population of brome plants tended to be smaller than those seen with other treatments and control of heads was similarly reduced. The use of these materials alone was insufficient to deliver effective control in the crop, however, their use within wider programmes and ‘stack’ and ‘sequence’ approaches was effective and can still be of value to growers. Chlorotoluron should only be used on suitable varieties.

Atlantis (iodosulfuron-methyl-sodium + mesosulfuron-methyl), used experimentally in this context (and not approved for use on barley), resulted in very variable control across the three studies. While high levels of crop damage were not noted in assessments it is possible that transient damage may have allowed the brome to outcompete the crop during critical periods. These studies were not taken to yield. These experiments would not support the further development of the use of this material to control barren brome in barley.

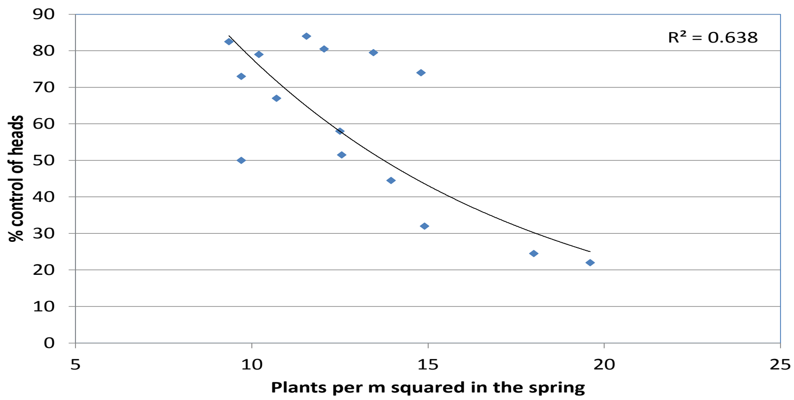

Figure 1. The effect of spring barren brome plant population in treated plots with the final reduction in head numbers. Mean data from Edinburgh and Aberdeen sites, 2011.

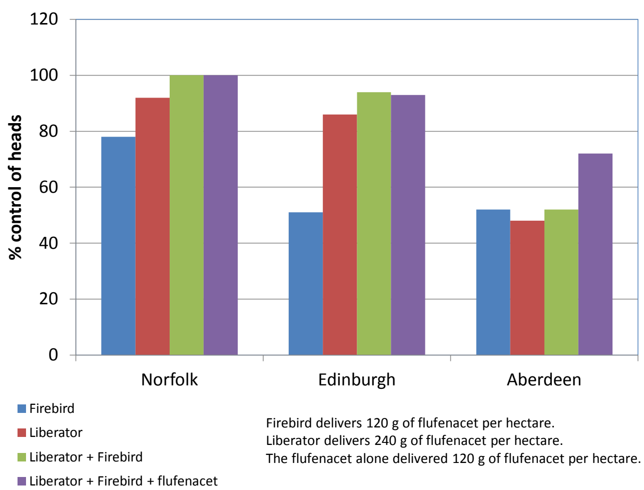

Figure 2. The influence of incremental flufenacet dose of barren brome control. Mean data from Norfolk, Edinburgh and Aberdeen sites, 2011, for % control of brome heads (all products applied pre-emergence).

3.4.3 Barren Brome – winter wheat

The degree of reduction achievable in barren brome plant and head numbers in winter wheat is dependent on the initial population. While data collected in the series of field experiments outlined in this report demonstrates in excess of 90% reduction in barren brome plants / heads across a wide range of brome populations, the number of brome plants / heads remaining at high population levels can still be considerable. This is important as even low levels of brome species (10 plants m^{-2}) can result in field losses of around 8% in winter wheat (see HGCA Information Sheet 7 for further details), with more severe losses associated with higher levels of infestation. Particularly where brome populations are high non-chemical management practices should also be considered.

Over the range of barren brome populations examined across this trial series 'stack' and 'sequence' approaches tended to deliver higher levels of control compared to the use of single actives ingredients or timings. The active ingredients tri-allate (Avadex Excel), flufenacet (e.g. in Liberator, Firebird and other herbicides), prosulfocarb (Defy) and chlorotoluron (various products) feature commonly among the more effective autumn programmes. The use of suitable ALS inhibiting products with a label recommendation for brome (e.g. products containing pyroxsulam or mesosulfuron + iodosulfuron) were also effective. 'Stack' and 'sequence' approaches tended to deliver the most consistent reductions to barren brome plants / head numbers and, particularly where brome pressure was high, the use of ALS inhibitor materials was important within these approaches.

With regard to active ingredients, as with barren brome control in winter barley, the active ingredient flufenacet was common to many of the more effective programmes and a dose response was seen. Increasing flufenacet dose from 240 g ai /ha to 360 g ai /ha tended to improve control although there was little further benefit from going to 480 g ai/ha. For example as follows in the East Hermiston 2011 experiment -

- flufenacet 240 g ai/ha (Liberator): 69% control of brome heads,
- flufenacet 360 g ai/ha (Liberator and Firebird): 84% control of brome heads,
- flufenacet 480 g ai/ha (Liberator, Firebird and additional flufenacet): 85% control of brome heads.

Avadex Excel (tri-allate) also gave useful levels of control of barren brome across a range of weed pressures, particularly when used in 'stack' and 'sequence' approaches. Similarly chlorotoluron provided useful control when used in 'stack' and 'sequence' approaches, but delivered control inferior to many autumn pre-emergence treatments when used alone even in low pressure scenarios. Chlorotoluron should only be used on suitable varieties.

The impact of barren brome pressure on the programme required to deliver control is best illustrated by considering data across several experiments; a collation of this data is as presented in Table 18. In low pressure barren brome scenarios the use of an ALS inhibitor product alone (e.g. pyroxsulam in Broadway Star) or the use of a suitable autumn residual herbicide programme can substantially reduce brome head numbers and deliver acceptable control. However, in higher pressure situations more robust programmes are required, generally involving higher input approaches including residual and ALS inhibitor components; there are a number of combinations of options available to deliver effective control of barren brome in these scenarios.

The cost of achieving effective brome control will depend on the weed spectrum and pressure in a particular situation, however, many of the materials highlighted as suitable for delivering control of barren brome will also provide useful control of other grass (e.g. annual meadow grass) and broadleaf weeds; although some modification of timing, doses and approach may be required. In higher pressure situations, some of the more robust residual and ALS inhibitor 'stack' and 'sequence' approaches will incur a higher cost. In very high pressure situations even very intensive programmes may not reduce populations to level that would not compromise yield; additional none chemical control routes will be required in these situations.

Table 18 The control of brome (head m^{-2}) achieved in a selected range of approaches and sites (data rounded whole numbers, full data presented in Tables 6-8).

Location	Norfolk (2010)	East Hermiston (2011)	Norfolk (2011)	East Hermiston (2010)
Untreated	814	280	57	10
Liberator	352	87	12	4
Broadway Star	491	29	2	0
Liberator fb Broadway Star	243	2	0	0
Liberator fb chlorotoluron	121	-	-	3
Liberator + Avadex Excel fb chlorotoluron	51	-	-	1
Liberator + Avadex Excel fb Atlantis	57	-	-	1

3.4.4 Black-grass – winter oilseed rape

The choice of residual grass weed herbicides for use in oilseed rape is becoming increasingly limited and there is concern over water pollution arising from some key active ingredients (e.g. metazachlor, carbetamide and propyzamide). However, oilseed rape presents a key opportunity for managing black-grass in the rotation, not least because carbetamide and propyzamide are not affected by resistance in black-grass.

Considering pre-emergence herbicide options in winter oilseed rape, metazachlor has traditionally been used in this position; either as a straight product, such as Butisan S and others, or in a range on related products typically containing further active ingredients often to address specific broadleaf weed issues. However, recent changes have limited the amount of this metazachlor than can be used in a given period of time. Research within this programme has evaluated other options that can be used in this window, specifically older chemistry, such as napropamide (Devrinol T) and tri-allate (Avadex Excel). Summary data presented in Table 19 indicated that on average all three products, when used at commonly applied doses, will deliver similar control of black-grass plants. However, when used alone performance of these products can vary (notably with Devrinol T although the reason for this variation is not clear). The level of control achieved was, on average, only around 40 - 45%. This level of control is unlikely to be sufficient, unless black-grass populations are very low, and will need to be augmented though other routes.

The potential for stacks of pre-emergence products has been evaluated within this research programme. Summary data presented in Table 19 comparing Butisan S or Devrinol T applied alone with the control achieved through a combination of the two herbicides indicates improvements can be achieved through this route. However, in general levels of control achieved have still typically been inferior to the stronger approaches based around carbetamide and propyzamide (over the same trial series averaging 75% and 88% control of black-grass plants respectively when applied at full dose). This is further illustrated in through the presentation of selected data in Figure 3, highlighting the performance of stacking approaches in 2011 in Wiltshire compared to a ‘Butisan S followed by Kerb Flo’ standard approach.

To this end the most effective control programmes have generally required propyzamide and/or carbetamide; clearly demonstrating their continued importance. Both dose and timing are important in maximising the performance of these two materials. Figure 4 presents summary data on timing for both propyzamide (Kerb Flo) and carbetamide (Crawler) averaged over 2 sites in 2009; both herbicides gave the greatest reduction in black-grass plant numbers when applied in November compared to earlier applications (as soil and weather conditions become more conducive to the activity of these herbicides). However the improvement seen in relation to Kerb Flo was more marked that that seen for Crawler. This Figure also depicts a comparison of control from Kerb Flo applied at 2.1 l/ha a range of timings, indicating the following levels of black-grass survival - October (55 plants m^{-2}), November (25 plants m^{-2}) and January (63 plants m^{-2}); the November timing clearly giving the highest level of control. Considering dose responses in November from the application of Kerb Flo, black-grass survival was as follows; 2.1 l/ha (25 plants m^{-2}), 1.7 l/ha (35 plants m^{-2}) and 1.4 l/ha (46 plants m^{-2}). While this indicates increasing control associated with higher doses, considered in conjunction with the timing information, it also suggests that a reduced dose at a time conducive to good efficacy can be as effective as a higher dose at a less favourable time. This could have important implications for both managing both black-grass populations and the potential movement of herbicides to water. Data on Kerb and Crawler response from 2011 (Table 11) averaged across all sites in that season shows a similar dose response for Kerb Flo, indicating that at a November timing Kerb Flo at 2.1 l/ha resulted in 96% control while 1.4 l/ha gave 89% control. With Crawler the pattern was the same but the differential was larger; 3.5 kg/ha applied in November giving 63% control while 2.3 kg/ha resulted in 49% control. This suggests greater dose flexibility in Kerb Flo compared to Crawler.

Figure 4 also outlines the potential for repeat sequences involving Kerb Flo and Crawler. Data clearly suggests that a Crawler (October) followed by Kerb (November) approach outperformed a repeated Kerb Flo approach. This would be in keeping with the stronger performance of Crawler (compared to Kerb Flo) at the October timing when these products were used alone. With regard to absolute performance however, data presented in Table 19 suggests that this approach was only delivering similar control to the full dose of Kerb Flo used alone in these experiments, although further work on dose and timing of this 'sequence' based technique could potentially deliver further improvements to this approach.

In terms of maximising overall black-grass control the strongest approaches tended to be the use of an appropriately timed autumn residual (such as propyzamide or carbetamide) in 'stack' or 'sequence' with other herbicides. This approach could be in conjunction with an appropriate graminicide (e.g. Laser, cycloxydim); for example data from 2009 (Table 9) indicted that Kerb Flo (1.7 l/ha) gave on average 72% control of black-grass plants when used alone, however this increased to 85% when used in conjunction with Laser. However, the strongest approaches tended to occur when used in conjunction with a pre-emergence residual herbicide; for example data presented in Table 19 indicated the benefit of a Butisan S followed by Kerb Flo approach (averaging 93% reduction in black-grass plants) compared to Kerb Flo alone (averaging 88% reduction at 2.1 l/ha).

The cost of achieving effective black-grass control in oilseed rape will depend on the pressure in particular situations, however, given the rotational importance of this crop and the opportunity afforded by propyzamide or carbetamide to manage resistant black-grass, the wider rotational benefit of any costs should be considered. Where black-grass pressure is high consideration should also be given to cultural control options and novel approaches for grass-weed management in oilseed rape (e.g. those being investigated in HGCA project RD-2009-3605 'New approaches to weed control in oilseed rape').

Table 19 The percent control of black-grass plants in oilseed rape achieved in a selected range of approaches and sites (full data presented in Tables 9-11).

			2009	*2009*	*2010*	*2011*	*2011*	
Treatment	*Dose (l/ha)*	*Timing*	*Lincs (Great Carlton)*	*Lincs (Orford)*	*Lincs*	*Wilts*	*Lincs*	*Mean*
Butisan S fb Kerb Flo[a]	1.5 l/ha fb 2.1 l/ha	Pre-em fb Mid Nov	87	90	95	95	96	93
Butisan S	1.5 l/ha	Pre-em	28	50	63	26	41	42
Devrinol	2.8 l/ha	Pre-em	65	65	50	9	9	40
Avadex Excel	15 kg/ha	Pre-em	43	47	65	48	25	46
Butisan S + Devrinol	1.5 l/ha + 2.8 l/ha	Pre-em	76	82	65	38	29	58
Kerb Flo	1.4 l/ha	Mid Nov	62	81	93	89	88	83
Kerb Flo	2.1 l/ha	Mid Nov	71	91	88	96	96	88
Crawler	3.5 kg/ha	Mid Nov.	75	99	74	44	81	75
Crawler fb Kerb Flo[b]	2.3 kg/ha fb 1.4 l/ha	Mid Oct fb Mid-Nov	66	90	96	91	99	88

Notes
a – in 2009 the dose of Kerb Flo used was 1.7 l/ha
b – in 2009 the doses of Kerb Flo was 1.05 l/ha and Crawler 1.75 kg/ha

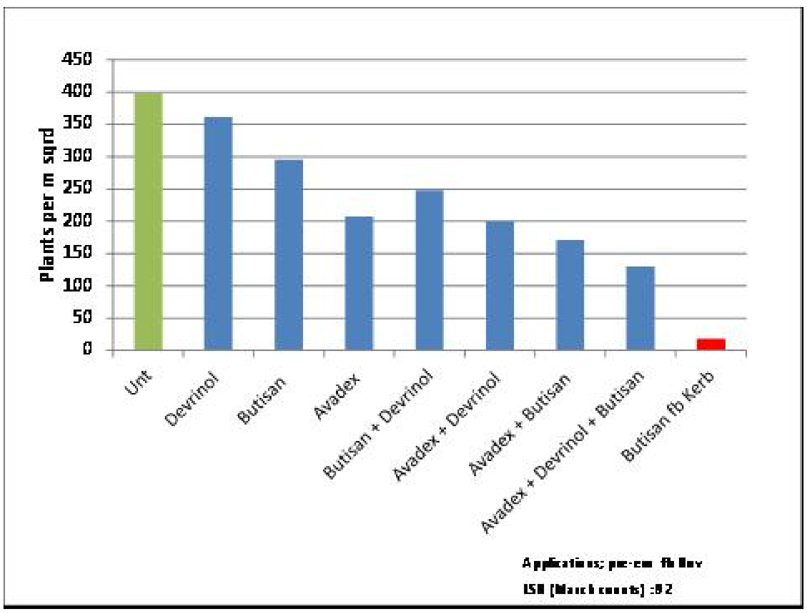

Figure 3. The impact of herbicide stacking approaches on the control of black-grass plants in oilseed rape from Wiltshire, 2011. All products applied pre-emergence with the exception of Kerb Flo (full data presented in Table 11). All active ingredients as outlined in Table 2.

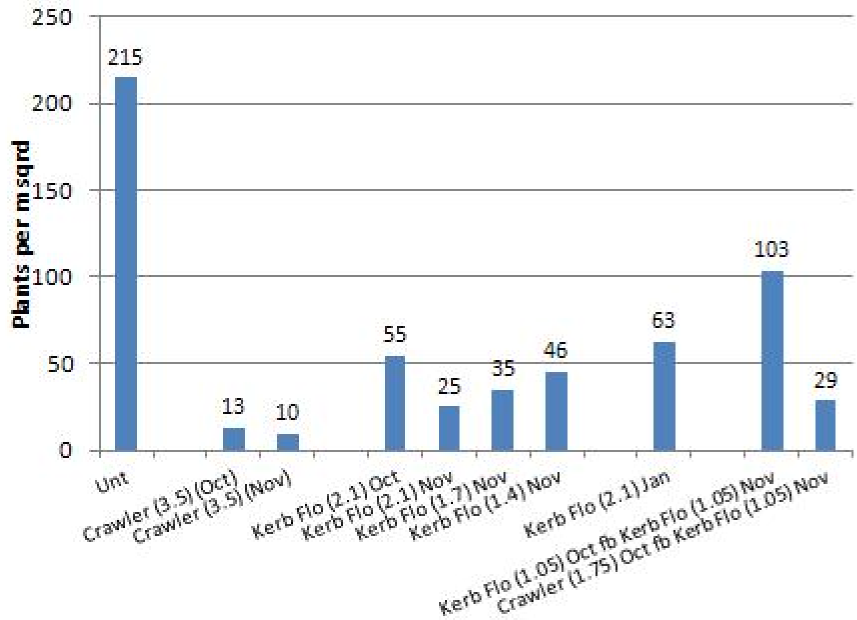

Figure 4. The impact of timing and dose on the performance of propyzamide (Kerb Flo) and carbetamide (Crawler) averaged over 2 sites in 2009 (data presented in Table 9). All active ingredients as outlined in Table 2.

3.4.5 Black-grass – winter barley

Herbicide approaches for the management of black-grass in winter barley tend to be similar to those used in winter wheat, with the notable exception of later post emergence options based on ALS inhibitor materials. This places a high reliance of the use of residual herbicides used either pre- or early post emergence and on the higher competitive ability of a healthy barley crop (compared to a wheat crop).

Table 20 summaries the data presented previously on the common pre- and early post treatments across the three studies set out in Tables 12 and 13. With regard to reduction in black-grass plants, treatments involving flufenacet (a constituent of both Crystal and Liberator) gave the higher levels of control, and this response pattern was carried though to reduction in final head number reductions. Considering in more detail the control given through Crystal and Liberator, data from 2008 (Table 12) also includes comparisons with pendimethalin (1200 g ai /ha) and diflufenican (Hurricane at 0.12 l/ha) applied alone (i.e. delivering the same doses of these active ingredients included in Crystal and Liberator). This suggests that control ostensibly stemmed from the flufenacet component of these materials, specifically:

- Untreated (30.2 plants m^{-2})
- Crystal (2.0 plants m^{-2}); pendimethalin (19 plants m^{-2})
- Liberator (5.7 plants m^{-2}); Hurricane (49 plants m^{-2})

With regard to prosulfocarb (Defy); Table 20 would suggest control was lower than that achieved with the flufenacet based products. However, data from 2008 (Table 12) would suggest that where prosulfocarb was used pre-emergence in conjunction with pendimethalin (analogous to the flufenacet + pendimethalin ‘stack’ in Crystal) the reduction in black-grass plants and head was markedly improved giving similar plant and head control to Crystal used alone in the same study. In addition in 2011 prosulfocarb was examined alone both pre- and early post emergence, use post emergence improved control by around 50%; possibly suggesting the material is well suited to this position. The potential offered is noteworthy as it provides an alternative to flufenacet based approaches. Data gathered in 2011 would also suggest that tri-allate (Avadex Excel) should be a useful material for black-grass control programmes in winter barley.

In general the more robust programmes for the management of black-grass in winter barley have involved ‘stack’ and ‘sequence’ approaches. This has tended to deliver higher levels of control compared to the use of single actives ingredients or timings; even at low populations. An example of a ‘stack’ and ‘sequence’ based approach, based on data collected in 2011, using both prosulfocarb and flufenacet is presented in Figure 5. While flufenacet tended to feature in the approaches delivering the higher levels of control the research demonstrates a series of routes to develop ‘stack’ and ‘sequence’ strategies; this might include, but not be limited to, building blocks such as prosulfocarb, tri-allate, chlorotoluron, pinoxaden, diflufenican and flurtamone.

It is noteworthy that in excess of 90% control of black-grass heads in winter barley could be achieved with populations of around 100 heads m^{-2} (Table 12) in untreated plots. This finding is a similar level to that seen in winter wheat using analogous stacking and sequencing techniques. In wheat 100 heads m^{-2} presented an upper range where ‘stacking’ and ‘sequencing’ could deliver effective control. In barley the higher crop competition may also help to augment this control (potentially resulting in fewer black-grass heads per plant than might be expected in an analogous scenario in winter wheat from the same black-grass plant population).

The cost of achieving effective black-grass control in winter barley will depend on the pressure in a particular scenario; however, many of the materials highlighted as suitable for delivering black-grass control will also provide useful control of other grass (e.g. annual meadow grass) and broadleaf weeds (although black-grass control may often require some changes of practice e.g. higher doses). The financial importance of black-grass is clear given it is estimated that yield losses in cereal crops of the order of 5% can be expected from 100 black-grass heads m^{-2} (Blair *et al*., 1999). Where black-grass pressure is high consideration should also be given to cultural control options.

Table 20 Percentage control of black-grass plants and heads in winter barley achieved in a selected range of approaches and sites (full data presented in Tables 12-13).

			Plants (% control)				*Heads (% control)*			
			2008	*2011*	*2011*		*2008*	*2011*	*2011*	
Treatment	*Dose (l/ha)*	*Timing*	*Lincs*	*Lincs*	*Beds*	*Mean*	*Lincs*	*Lincs*	*Beds*	*Mean*
Untreated	(m^{-2})		(30)	(24)	(14)	(23)	(108)	(50)	(39)	(66)
Defy	5.0	Pre-em	60	54	0	38	23	71	2	32
Liberator	0.6	Pre-em	81	67	72	73	57	49	57	55
Crystal	4.0	Pre-em	93	89	78	87	89	98	27	71
Lexus	20 g/ha	Pre-em	5	50	54	36	32	0	73	35
Graduate	0.625	1-2 leaf	23	7	0	10	11	43	0	18

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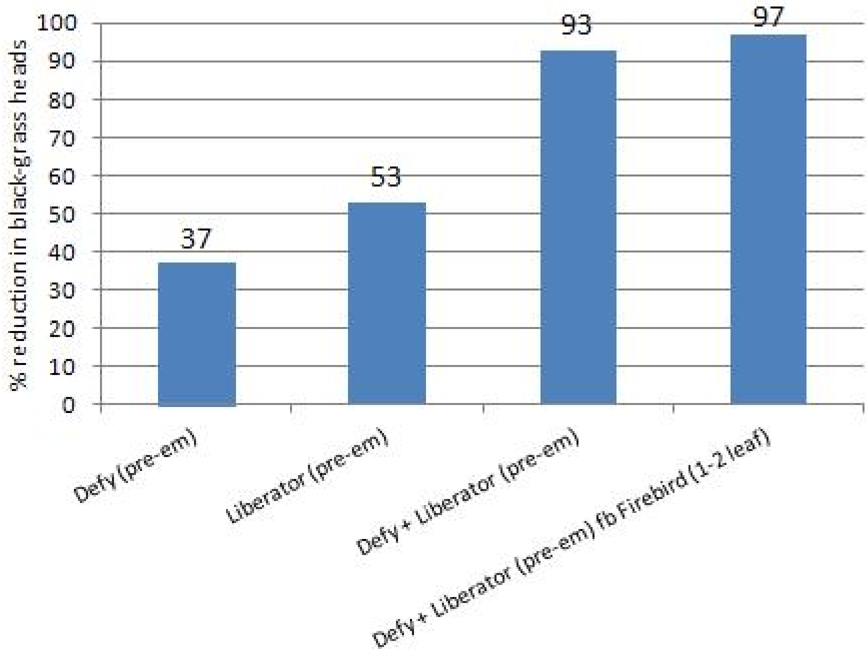

Figure 5. An example of incremental control of black-grass heads in winter barley based on mean data from two sites in 2011 (data presented in Table 13). All products used at full label rate, all active ingredients as outlined in Table 2.

3.4.6 Black-grass – winter wheat

Black-grass populations in winter wheat are becoming more difficult to control due to increasing herbicide resistance and reducing herbicide availability. This has resulted in increasing reliance on products containing iodosulfuron-methyl-sodium + mesosulfuron-methyl (e.g. Atlantis) for the high levels of control. The potential impacts of resistance to Atlantis on the levels of control achieved on farm are highlighted in section 3.3.6 and Table 16 of this report (although it should be acknowledged that the poor control in this experiment may have been exacerbated by cool conditions). Research addressing black-grass control in winter wheat in this project has sought to develop further alternative approaches based on available herbicides while also seeking not to place over reliance on remaining herbicides. The approaches used have ostensibly looked at ‘stacking’ and ‘sequencing’ techniques or combinations of the two routes.

Considering the overall levels of control achieved through these methods across a range of studies and seasons the percentage reduction on fertile tillers achieved by these routes would appear to be associated with the size of the black-grass infestation (Stobart 2009; Stobart and Orson 2011). Cumulative data for 2008, 2009 and 2010 is summarised in Table 21; this suggests that the level of control was higher where the populations of fertile tillers in the untreated plots were low. This may have been due to intra-specific competition as there are fewer fertile tillers on individual black-grass plants as populations increase. For example, in high populations of black-grass plants, following the same reduction in plant numbers there will be capacity for a greater capacity for the development of fertile tillers (head numbers) on the surviving plants compared with the same percentage reduction of a low population of plants; this will result in a lower control of fertile tillers in the high population (Orson, 2011). The finding would suggest that where populations in untreated plots exceed approximately 100 heads m^{-2} (possibly 10–15 surviving plants m^{-2}) the level of control offered through stacking and sequencing approaches is likely to be diminished and are unlikely to offer >95% reductions in black-grass heads. When data from 2011 is included in the same format results would suggest that in excess of 95% reduction on black-grass heads can be achieved at populations of approximately 250 heads m^{-2} in untreated plots (Table 22). This should, however, be treated with some caution and viewed in the context of the season where later drilling, hard winter conditions and exceptionally dry spring reduced tiller survival in black-grass and augmented the control achieved with herbicide programmes.

It seems apparent from this data that in very high black-grass pressure situations even very intensive ‘stacking’ and ‘sequencing’ programmes will not reduce populations to commercially acceptable levels that would not be expected to compromise yield; additional cultural control routes will be required in these situations.

With regard to pre- and early post emergence herbicide options, Table 23 summaries the performance of a series of treatments common to a range of studies in this research programme. Data is presented as the percentage reduction in black-grass head numbers (the black-grass level in untreated plots is also stated). While there will undoubtedly be an interaction between performance and the conditions at application, considering the general trends and comparing flufenacet + pendimethalin (Crystal), flufenacet + diflufenican (Liberator), prosulfocarb (Defy) and tri-allate (Avadex Excel), the ranking order based on mean levels of control across all studies was Crystal (58% reduction), Avadex Excel (from a more limited data set, 49% reduction), Liberator (46% reduction) and Defy (33% reduction). Where Liberator and Defy were used as a ‘stack’ or Liberator and additional flufenacet based materials (i.e. Liberator + Crystal or Liberator + flufenacet) used as a ‘sequence’ the mean reduction in black-grass head numbers increased to 71% and 72% respectively. At low to moderate populations these approaches gave in excess of 95% control in 5 out of 10 comparisons with an average control of 89% mean reduction in black-grass heads. . Comparing Crystal and Defy applied at peri-emergence with the same materials used pre-emergence; the control achieved through Defy increased from 30% to 51% reduction in black-grass and was similar to Crystal applied peri-em (57% reduction compared to 56% from pre-emergence use in common seasons). The use of flurtamone + diflufenican (Graduate) used early post emergence resulted in a mean reduction in black-grass head numbers of 24%.

It is clear that the use of pre-emergence herbicides alone is unlikely to deliver adequate control and combinations through ‘stacks’ and ‘sequences’ will be required in most scenarios. The previously cited use of a Liberator and Defy mix or Liberator and additional flufenacet programme are two examples of ‘stack’ and ‘sequence’ approaches. Within the experimental series a variety of other ‘stack’ and ‘sequence’ approaches have been explored and research has demonstrated a range of routes to deliver black-grass control through these mechanisms; in general at least 3 active ingredients were needed in the more successful approaches. Flufenacet is an important active ingredient and incremental doses of this active have been shown to improve the control of black-grass (data summarising this are presented in Table 24); although the reduction in final head numbers achieved tends to decline in line with increasing black-grass head numbers in untreated plots. The use of flufenacet has been integral to many of the stronger ‘stack’ and ‘sequence’ approaches; for example see summary data presented in Figure 6. However, over reliance on any single active ingredient is of concern and approaches have also demonstrated how non-flufenacet based routes, such as those based around tri-allate (Avadex Excel) and prosulfocarb (Defy) can also be very effective; as highlighted by data presented in Figure 7. A range of other active ingredients have also featured in specific ‘stack’ and ‘sequence’ approaches, including (but not limited to) chlorotoluron, flurtamone and diflufenican. It is worth noting that these approaches also resulted in a high percentage reduction in black-grass heads even where ALS resistance (resistance to Atlantis) was present. Research has shown little difference between ‘stack’ and ‘sequence’ approaches. For example, data presented in Table 15 suggests that a ‘sequence’ of Crystal (flufenacet + pendimethalin) applied pre-emergence and Defy (prosulfocarb) applied early post emergence was not significantly different in reducing the number of black-grass heads than applying the two together pre-emergence. Other examples are also present within the data set. However, at times, it may be expected that a 'sequence' of active ingredients will be more effective than a 'stack' (single application) of the same active ingredients. For example, sometimes active ingredients may be more effective when applied as components of a 'sequence', in conditions that are suited to herbicide activity, than when applied as a 'stack' at a single timing, when conditions may be less favourable.

Given residual herbicides are, to varying degrees, are sensitive to soil conditions at the time of application, the very dry soil conditions at the time of application of the pre- and early post-emergence applications at the Lincolnshire (2010) appear to have influenced the relative performance of the individual products when compared to the other experiments in the project (Table 16). Specifically flufenacet + diflufenican (Liberator) provided particularly low levels of control with prosulfocarb (Defy) and flufenacet + pendimethalin (Crystal) providing a greater reduction in fertile tiller numbers. Treatments based on tri-allate (Avadex Excel) were successful in relative terms, whilst those containing chlorotoluron + diflufenican resulted in particularly low levels of control when applied when the soil surface was very dry. This may have been associated with the vapour pressure and the Henry's constant (dimensionless) of the active ingredients. Those which provided relatively better control under dry soil conditions have higher vapour pressures and Henry's constant (dimensionless) values which perhaps resulted in their availability being less dependent on soil moisture conditions (Stobart and Orson, 2011). Similar trends can also be seen from the black-grass ground cover data from the Bedfordshire site in the same season.

The black-grass pressure in a particular scenario will be main driver behind the cost of achieving effective control in winter wheat. In high pressure situations it is likely chemical control alone will be insufficient and additional cultural control techniques will be needed. With regard to 'stacking' and 'sequencing' techniques these are most likely to be successful at low to moderate levels of black-grass (possibly fewer than 100 heads m^{-2} or around 10-15 plants in untreated areas). The use of 'stacking' and 'sequencing' approaches may require an alteration herbicide strategy and timings for many growers compared to their current practice. Specifically the strong reliance on residual herbicides applied pre- or early post emergence will require materials to be applied either before or at early stages of black-grass emergence. While many growers will currently use pre-emergence herbicides, in most approaches the requirement for additional treatments at the two leaf stage of black-grass onwards has generally been based on crop inspection rather than likely burden. The switch to 'stacking' and 'sequencing' approaches will also require greater 'up front' investment in residual herbicide materials (whose activity can be influenced by soil conditions). However, 'stacking' and 'sequencing' techniques can also provide useful control of other grass (e.g. annual meadow grass) and broadleaf weeds. In addition data from this experimental series does suggest that these techniques are likely to remain effective where ALS resistance is a problem and as such deliver an alternative approach to growers (subject to maintaining black-grass populations at a level that is conducive to management through this approach).

The specific costs of 'stacking' and 'sequencing' will be influenced by the products used and the deals through which they are purchased, however such approaches are likely to be more expensive than many current strategies for many growers where ALS herbicides still provide good levels of control. For example, based on specimen prices at the time of writing, a pre-emergence Liberator (flufenacet + diflufenican) followed by Atlantis (iodosulfuron + mesosulfuron) programme may cost around £60–65 ha^{-1} (excluding application cost). However, a sample 'stack' approach based on Liberator and Defy (prosulfocarb) would be similar 'upfront cost' (around £60–65 ha^{-1}) while an additional 'sequence' applications, e.g. those based around chlorotoluron, diflufenican, pendimethalin and/or flufenacet based products, would add further cost; possibly £10–30 ha^{-1} depending on specific inclusions. However, given yield losses in cereal crops of the order of 5% can be expected from around 100 black-grass heads m^{-2}, yield losses to even moderate levels of black-grass are likely outweigh any increased cost.

Table 21. % Black-grass head (fertile tiller) reduction in winter wheat from a wide range of pre-emergence and/or early post-emergence herbicide treatments, applied alone, in mixture or in sequences across a range of population densities, harvest years 2008–2010 (full data contained in tables 14-16, the figures exclude untreated and 'Atlantis' based programmes).

Black-grass head numbers m^{-2} (to the nearest whole number) in untreated plots	Number of treatments achieving the specified reduction in black-grass heads				
	Season	% reduction			
		>95%	75-94%	50-74%	<49%
1832	2010	0	0	0	23
782	2010	0	2	4	17
345	2008	0	0	1	20
222	2009	0	10	6	7
204	2008	0	1	10	10
78	2009	3	4	13	3
53	2008	3	6	7	5

Table 22. % Black-grass head (fertile tiller) reduction in winter wheat from a wide range of pre-emergence and/or early post-emergence herbicide treatments, applied alone, in mixture or in sequences across a range of population densities, harvest years 2008–2011 (full data contained in Tables 14–17, the figures exclude untreated and 'Atlantis' based programmes).

Black-grass head numbers m^{-2} (to the nearest whole number) in untreated plots	Number of treatments achieving the specified reduction in black-grass heads				
	Season	% reduction			
		>95%	75-94%	50-74%	<49%
1832	2010	0	0	0	23
782	2010	0	2	4	17
345	2008	0	0	1	20
247	2011	8	3	5	4
222	2009	0	10	6	7
204	2008	0	1	10	10
106	2011	1	10	4	5
78	2009	3	4	13	3
53	2008	3	6	7	5

Table 23 Percentage control of black-grass heads in winter wheat achieved over a range of approaches and sites (full data presented in Tables 14–17 active ingredients in products as outlined in Table 2).

Treatment	*Dose (l ha^{-1})*	*Timing*	*Suffolk (08)*	*Wilts (09)*	*Lincs (11)*	*Lincs (08)*	*Lincs (09)*	*Hants (11)*	*Wilts (08)*	*Lincs (10)*	*Beds (10)*	*Mean*
Untreated plants (m^{-2})			53	78	106	204	222	247	344	782	1832	
Crystal	4.0	Pre-em	74	65	88	39	79	95	23	52	8	58
Defy	5.0	Pre-em	20	53	30	0	50	68	19	28	28	33
Liberator	0.6	Pre-em	89	62	64	63	44	66	15	7	6	46
Liberator + Defy	0.6 + 5.0			97	83		75	100		46	27	71
Liberator fb Crystal	0.6 + 4.0		100	96		60	90		50	-	-	
Liberator fb flufenacet*	0.6 + 240 g ai/ha	Pre-em	-	-	89	-	-	100	-	41	18	72
Avadex Excel	15 kg/ha	Pre-em			74			64		44	12	49
Crystal	4.0	Peri-em	94	65	-	19	76	-	32	-	-	57
Defy	5.0	Peri-em	72	55	-	54	65	-	18	-	-	53
Graduate	0.625	1-2 leaf	29	39	47	0	27	35	23	4	11	24

* Additional flufenacet either applied as straight flufenacet or as Firebird plus additional flufenacet (see Tables 14-17).

Table 24. Percentage control of black-grass heads in winter wheat from a range of incremental flufenacet doses over selected sites in 2010 and 2011 (full data presented in Tables 16 and 17, active ingredients in products as outlined in Table 2).

Treatment	*Dose (l ha^{-1})*	*Lincs (11)*	*Hants (11)*	*Lincs (10)*	*Beds (10)*	*Mean*
Untreated plants (m^{-2})		106	247	782	1832	
Liberator	0.6	64	66	7	6	36
Liberator fb Firebird	0.6 fb 0.3	83	99	28	12	56
Liberator fb Firebird + flufenacet	0.6 fb 0.3 + 240 g ai/ha	89	100	41	18	62

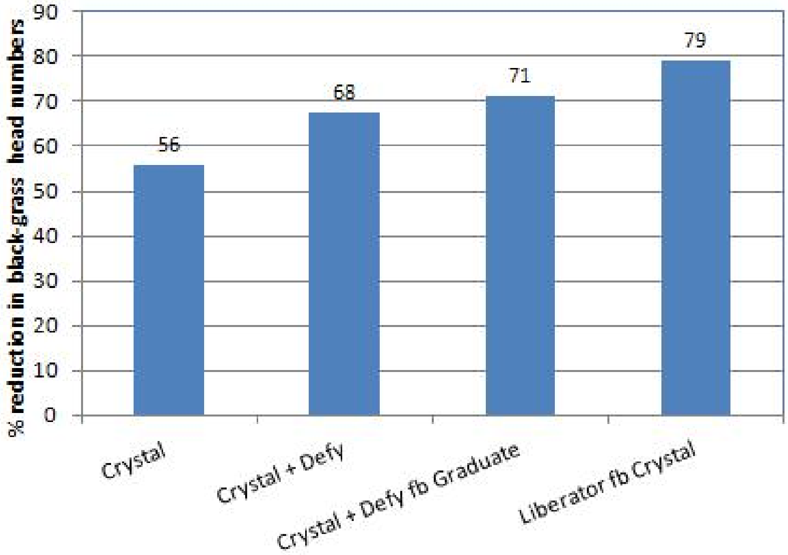

Figure 6. An example of incremental control of black-grass heads in winter wheat based on mean data from a 5 site mean across experiments in 2008 and 2009 (data presented in Tables 14 and 15). Data presented as a percentage reduction in black-grass heads compared to untreated plots. All products used at full label rate, all active ingredients as outlined in Table 2.

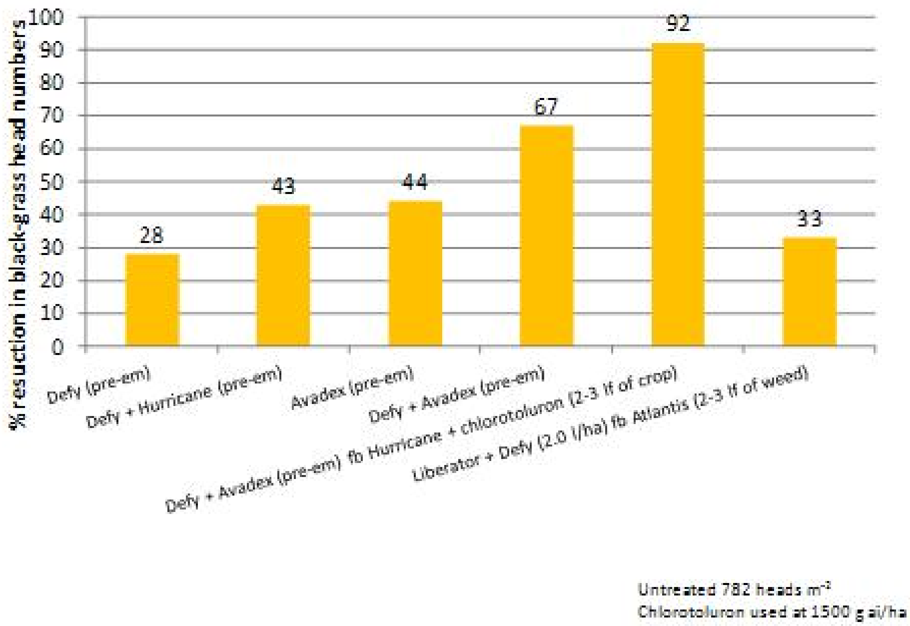

Figure 7. An example of incremental control of black-grass heads in winter wheat based Lincolnshire 2010 (full data presented in Tables 16). All products used at full label rate, all active ingredients as outlined in Table 2.

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3.6 References

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Appendix A – Treatment listing including active ingredient doses for all experiments

Table A1. Treatment list for experiments addressing black-grass in winter wheat in the 2007/08 season.

	Treatment	*Dose (l/ha)*	*Timing*	*active ingredient*	*concentration*	*dose of active per ha*
1.	Untreated					
2.	Untreated					
3.	Crystal + trifluralin fb Atlantis (+ Biopower)	4.0 l/ha + 2.3 l/ha fb 0.4kg/ha	Pre-em Pre-em 2-3 leaf (weed)	flufenacet + pendimethalin trifluralin mesosulfuron-methyl + iodosulfuron-methyl-sodium	60 g/l + 300 g/l 480 g/l 30 g/l + 6 g/l	240 g + 1200 g 1104 g 12 g + 2.4 g
4.	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
5.	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
6.	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	400 g/l + 100 g/l	240 g + 60 g
7.	Graduate	0.625 l/ha	Pre-em	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
8.	Guillotine	0.1 l/ha	1 leaf	flumioxazine	300 g/l	30 g
9.	Defy + pendimethalin	5.0 l/ha + 1200 g ai/ha	Pre-em Pre-em	prosulfocarb pendimethalin	800 g/l -	4000 g 1200 g
10.	Crystal + Defy	4.0 l/ha + 5.0 l/ha	Pre-em	flufenacet + pendimethalin prosulfocarb	60 g/l + 300 g/l 800 g/l	240 g + 1200 g 4000 g
11.	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
12.	Hurricane	0.12 l/ha	Pre-em	diflufenican	500 g/l	60 g
13.	Hurricane	0.25 l/ha	Pre-em	diflufenican	500 g/l	125 g
14.	pendimethalin	1200 g ai/ha	Pre-em	pendimethalin	-	1200 g
15.	pendimethalin	1980 g ai/ha	Pre-em	pendimethalin	-	1980 g
16.	Crystal	4.0 l/ha	Peri-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
17.	Defy	5.0 l/ha	Peri-em	prosulfocarb	800 g/l	4000 g
18.	Graduate	0.625 l/ha	1 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
19.	Liberator fb Crystal	0.6 l/ha fb 4 l/ha	Pre-em Peri-em	flufenacet + diflufenican flufenacet + pendimethalin	400 g/l + 100 g/l 60 g/l + 300 g/l	240 g + 60 g 240 g + 1200 g
20.	Crystal fb Defy	4.0 l/ha fb 5.0 l/ha	Pre-em Peri-em	flufenacet + pendimethalin prosulfocarb	60 g/l + 300 g/l 800 g/l	240 g + 1200 g 4000 g
21.	Defy fb Crystal	5.0 l/ha fb 4.0 l/ha	Pre-em Peri-em	prosulfocarb flufenacet + pendimethalin	800 g/l 60 g/l + 300 g/l	4000 g 240 g + 1200 g
22.	Crystal fb Graduate	4.0 l/ha fb 0.625 l/ha	Pre-em 1 leaf	flufenacet + pendimethalin flurtamone + diflufenican	60 g/l + 300 g/l 400 g/l + 80 g/l	240 g + 1200 g 250 g + 50 g
23.	Crystal + Defy fb Graduate	4.0 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em 1 leaf	flufenacet + pendimethalin prosulfocarb flurtamone + diflufenican	60 g/l + 300 g/l 800 g/l 400 g/l + 80 g/l	240 g + 1200 g 4000 g 250 g + 50 g
24.	Crystal fb Defy fb Graduate	4.0 l/ha fb 5.0 l/ha fb 0.625 l/ha	Pre-em Peri-em 1 leaf	flufenacet + pendimethalin prosulfocarb flurtamone + diflufenican	60 g/l + 300 g/l 800 g/l 400 g/l + 80 g/l	240 g + 1200 g 4000 g 250 g + 50 g

Table A2. Treatment list for experiments addressing black-grass in winter barley in the 2007/08 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated					
2.	Untreated					
3.	Liberator fb IPU + Stomp 400	0.6 l/ha fb 2500 g/ha ai + 3.0 l/ha	Pre-em 1-2 leaf 1-2 leaf	flufenacet + diflufenican isoproturon pendimethalin	400 g/l + 100 g/l - 400 g/l	240 g + 60 g 2500 g 1200 g
4.	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
5.	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
6.	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	400 g/l + 100 g/l	240 g + 60 g
7.	Lexus	20g/ha	Pre-em	flupyrsulfuron-methyl	50% w/w	10 g
8.	Graduate	0.625 l/ha	Pre-em	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
9.	Defy + pendimethalin	5.0 l/ha + 1200 g ai/ha	Pre-em	prosulfocarb pendimethalin	800 g/l -	4000 g 1200 g
10.	Defy + Lexus	5.0 l/ha + 20 g/ha	Pre-em	prosulfocarb flupyrsulfuron-methyl	800 g/l 50% w/w	4000 g 10 g
11.	Crystal + Defy	4.0 + l/ha + 5.0 l/ha	Pre-em	flufenacet + pendimethalin prosulfocarb	60 g/l + 300 g/l 800 g/l	240 g + 1200 g 4000 g
12.	Crystal + Lexus	4.0 l/ha + 20 g/ha	Pre-em	flufenacet + pendimethalin flupyrsulfuron-methyl	60 g/l + 300 g/l 50% w/w	240 g + 1200 g 10 g
13.	Crystal fb Liberator	4 l/ha fb 0.6 l/ha	Pre-em 1-2 leaf	flufenacet + pendimethalin flufenacet + diflufenican	60 g/l + 300 g/l 400 g/l + 100 g/l	240 g + 1200 g 240 g + 60 g
14.	Hurricane	0.12 l/ha	Pre-em	diflufenican	500 g/l	60 g
15.	pendimethalin	1200 g ai/ha	Pre-em	pendimethalin	-	1200 g
16.	Graduate	0.625 l/ha	1-2 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
17.	Crystal fb Graduate	4.0 l/ha fb 0.625 l/ha	Pre-em 1-2 leaf	flufenacet + pendimethalin flurtamone + diflufenican	60 g/l + 300 g/l 400 g/l + 80 g/l	240 g + 1200 g 250 g + 50 g
18.	CTU + Stomp 400	3500 g ai/ha + 3.0 l/ha	1-2 leaf	chlorotoluron pendimethalin	90% w/w 400 g/l	3500 g 1200 g
19.	Liberator fb CTU + Stomp 400	0.6 l/ha fb 3500 g/ha ai + 3.0 l/ha	Pre-em 1-2 leaf 1-2 leaf	flufenacet + diflufenican Chlorotoluron pendimethalin	400 g/l + 100 g/l 90% w/w 400 g/l	240 g + 60 g 3500 g 1200 g
20.	Crystal fb CTU + Hurricane	4.0 l/ha fb 3500 g/ha ai + 0.12 l/ha	Pre-em 1-2 leaf 1-2 leaf	flufenacet + pendimethalin chlorotoluron diflufenican	60 g/l + 300 g/l 90% w/w 500 g/l	240 g + 1200 g 3500 g 60 g
21.	Liberator fb Axial (+ Adigor) + Stomp 400	0.6 l/ha fb 0.45 l/ha + 3.0 l/ha	Pre-em 1-2 leaf 1-2 leaf	flufenacet + diflufenican pinoxaden pendimethalin	400 g/l + 100 g/l 100 g/l 400 g/l	240 g + 60 g 45 g 1200 g

Table A3. Treatment list for experiments addressing black-grass in winter oilseed rape in the 2007/08 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated	-	-			
2.	Untreated	-	-			
3.	Butisan S + trifluralin fb Kerb Flo	1.5 l/ha + 2.3 l/ha fb 2.1 l/ha	Pre-em Pre-em Mid Nov	metazachlor trifluralin propyzamide	500 g/l 480 g/l 400 g/l	750 g 1104 g 840 g
4.	Butisan S	1.5 l/ha	Pre-em	metazachlor	500 g/l	750 g
5.	Butisan S	2.5 l/ha	Pre-em	metazachlor	500 g/l	1250 g
6.	Centium	0.33 l/ha	Pre-em	clomazone	360 g/l	118.8 g
7.	Devrinol	2.8 l/ha	Pre-em	napropamide	450 g/l	1260 g
8.	Butisan S + Devrinol	1.5 l/ha + 2.8 l/ha	Pre-em Pre-em	metazachlor napropamide	500 g/l 450 g/l	750 g 1260 g
9.	Butisan S fb Laser (+ adjuvant)	1.5 l/ha fb 0.8 l/ha	Pre-em Mid Oct	metazachlor cycloxydim	500 g/l 200 g/l	750 g 160 g
10.	Butisan S fb Kerb Flo	1.5 l/ha fb 1.7 l/ha	Pre-em Mid Nov	metazachlor propyzamide	500 g/l 400 g/l	750 g 680 g
11.	Kerb Flo	2.1 l/ha	Mid Oct	propyzamide	400 g/l	840 g
12.	Kerb Flo	2.1 l/ha	Mid Nov.	propyzamide	400 g/l	840 g
13.	Kerb Flo	2.1 l/ha	Late Jan.	propyzamide	400 g/l	840 g
14.	Kerb Flo	1.7 l/ha	Mid Nov.	propyzamide	400 g/l	680 g
15.	Kerb Flo	1.4 l/ha	Mid Nov	propyzamide	400 g/l	560 g
16.	Kerb Flo + Laser (+ adjuvant)	1.7 l/ha + 0.8 l/ha	Mid Nov Mid Nov	propyzamide cycloxydim	400 g/l 200 g/l	680 g 160 g
17.	Kerb Flo + Laser (+ adjuvant)	1.4 l/ha + 0.8 l/ha	Mid Nov	propyzamide cycloxydim	400 g/l 200 g/l	560 g 160 g
18.	Laser (+ adjuvant) fb Kerb Flo	0.8 l/ha fb 1.7 l/ha	Mid Oct Late Jan.	cycloxydim propyzamide	200 g/l 400 g/l	160 g 680 g
19.	Laser (+ adjuvant) fb Kerb Flo	0.8 l/ha fb 1.7 l/ha	Mid Oct Mid Nov	cycloxydim propyzamide	200 g/l 400 g/l	160 g 680 g
20.	Kerb Flo fb Kerb Flo	1.05 l/ha fb 1.05 l/ha	Mid Oct Mid Nov.	propyzamide propyzamide	400 g/l 400 g/l	420 g 420 g
21.	Crawler	3.5 kg/ha	Mid Oct	carbetamide	60 % w/w	2100 g
22.	Crawler	3.5 kg/ha	Mid Nov.	carbetamide	60 % w/w	2100 g
23.	Crawler + Laser (+ adjuvant)	3.5 kg/ha + 0.8 l/ha	Mid Nov Mid Nov	carbetamide cycloxydim	60 % w/w 200 g/l	2100 g 160 g
24.	Crawler fb Kerb Flo	1.75 kg/ha fb 1.05 l/ha	Mid Oct Mid-Nov	carbetamide propyzamide	60 % w/w 400 g/l	1050 g 420 g

Table A4. Treatment list for experiments addressing barren brome in winter wheat in the 2007/08 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated	-	-			
2.	Untreated	-	-			
3.	Untreated	-	-			
4.	Liberator fb Atlantis (+ Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em 2-3 leaf (weed)	flufenacet + diflufenican mesosulfuron-methyl + iodosulfuron-methyl-sodium	60 g/l + 300 g/l 30 g/l + 6 g/l	36 g + 180 g 12 g + 2.4 g
5.	Liberator fb Monitor	0.6 l/ha fb 25 g/ha	Pre-em Spring growth	flufenacet + diflufenican sulfosulfuron	60 g/l + 300 g/l 80% w/w	36 g + 180 g 20 g
6.	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
7.	Defy	5 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
8.	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	60 g/l + 300 g/l	36 g + 180 g
9.	Avadex Excel	15 kg/ha = 2,250g ai	Pre-em	tri-allate	15% w/w	2250 g
10.	Defy + Hurricane	5 l/ha + 0.12 l/ha	Pre-em Pre-em	prosulfocarb diflufenican	800 g/l 500 g/l	4000 g 60 g
11.	Hurricane	0.12 l/ha	Pre-em	diflufenican	500 g/l	60 g
12.	Hurricane	0.25 l/ha	Pre-em	diflufenican	500 g/l	125 g
13.	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
14.	pendimethalin (EC)	1,200g ai/ha	Pre-em	pendimethalin	-	1200 g
15.	isoproturon	2,500 g ai/ha	1-2 leaves	isoproturon	-	2500 g
16.	chlorotoluron	3,500 g ai/ha	1-2 leaves	chlorotoluron	-	3500 g
17.	Atlantis (+ Biopower)	0.4 kg/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium	30 g/l + 6 g/l	12 g + 2.4 g
18.	Avadex Excel fb Atlantis (+ Biopower)	15kg/ha = 2,250g ai fb 0.4 kg/ha	Pre-em 2-3 leaf (weed)	tri-allate mesosulfuron-methyl + iodosulfuron-methyl-sodium	15% w/w 6 g/l + 30 g/l	2250 g 24 g + 120 g
19.	Atlantis (+ Biopower) + Hurricane	0.4 kg/ha + 0.12 l/ha	2-3 leaf (weed) 2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium diflufenican	30 g/l + 6 g/l 500 g/l	12 g + 2.4 g 60 g
20.	Othello (+ Biopower)	1.0 l/ha	2-3 leaf (weed)	diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 g/l + 2.5 g/l + 7.5 g/l	50 g + 2.5 g + 7.5 g
21.	HGCA2 (+ adjuvant)	250 g/ha + (200 ml/ha + 500 ml/ha)	2-3 leaf (weed) 2-3 leaf (weed)	pyroxsulam	-	-
22.	HGCA2 (+ adjuvant)	250 g/ha + (200 ml/ha + 500 ml/ha)	Spring growth Spring growth	pyroxsulam	-	-
23.	Monitor	25 g/ha	Spring growth	sulfosulfuron	80% w/w	20 g
24.	Pacifica (+ BioPower)	0.5 kg/ha	Spring growth	iodosulfuron-methyl-sodium + mesosulfuron-methyl	1.0% w/w + 3.0% w/w	5 g + 15 g

Table A5. Treatment list for experiments addressing annual meadow grass in winter w in the 2007/08 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated	-	-			
2.	Untreated	-	-			
3.	isoproturon	1,000 g ai/ha	1-2 leaf	isoproturon	-	1000 g
4.	chlorotoluron	1,500 g ai/ha	1-2 leaf	chlorotoluron	-	1500 g
5.	Crystal	1.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	60 g + 300 g
6.	Crystal	2.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	120 g + 600 g
7.	Defy	1.5 l/ha	Pre-em	prosulfocarb	800 g/l	1200 g
8.	Defy	3.0 l/ha	Pre-em	prosulfocarb	800 g/l	2400 g
9.	Liberator + Hurricane	0.15 l/ha + 0.03 l/ha	Pre-em Pre-em	flufenacet + diflufenican diflufenican	60 g/l + 300 g/l 500 g/l	9 g + 45 g 15 g
10.	Liberator + Hurricane	0.3 l/ha + 0.06 l/ha	Pre-em Pre-em	flufenacet + diflufenican diflufenican	60 g/l + 300 g/l 500 g/l	18 g + 90 g 30 g
11.	Flight	2.0 l/ha	Pre-em	pendimethalin + picolinafen	330 g/l + 7.5 g/l	660 g + 15 g
12.	Bacara	0.6 l/ha	Pre-em	diflufenican + flurtamone	100 g/l + 250 g/l	60 g + 150 g
13.	Lexus	20 g/ha	Pre-em	flupyrsulfuron-methyl	50% w/w	10 g
14.	Guillotine	0.05 l/ha	1-2 leaf	flumioxazine	300 g/l	15 g
15.	Guillotine	0.1 l/ha	1-2 leaf	flumioxazine	300 g/l	30 g
16.	flufenacet	120 g ai/ha	Pre-em	flufenacet	-	120 g
17.	pendimethalin	600 g ai/ha	Pre-em	pendimethalin	-	600 g
18.	pendimethalin + Lexus	600 g ai/ha + 20 g/ha	Pre-em Pre-em	pendimethalin flupyrsulfuron-methyl	- 50% w/w	600 g 10 g
19.	pendimethalin (EC form)	1200 g ai/ha	Pre-em	pendimethalin	-	1200 g
20.	Hurricane	0.12 l/ha	Pre-em	diflufenican	500 g/l	60 g
21.	Defy + Lexus	3.0 l/ha + 20 g/ha	Pre-em Pre-em	prosulfocarb flupyrsulfuron-methyl	800 g/l 50% w/w	2400 g 10 g
22.	Defy + Lexus	1.5 l/ha + 20 g/ha	Pre-em Pre-em	prosulfocarb flupyrsulfuron-methyl	800 g/l 50% w/w	1200 g 10 g
23.	Othello (+ Biopower)	0.5 l/ha	2-3 leaf	diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 g/l + 2.5 g/l + 7.5 g/l	25 g + 1.25 g + 3.75 g
24.	Othello (+ Biopower)	1.0 l/ha	2-3 leaf	diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 g/l + 2.5 g/l + 7.5 g/l	50 g + 2.5 g + 7.5 g

Table A6. Treatment list for experiments addressing black-grass in winter wheat in the 2008/09 season.

	Treatment	*Dose (l/ha)*	*Timing*	*active ingredient*	*concentration*	*dose of active per ha*
1.	Untreated					
2.	Untreated					
3	Untreated					
4	Crystal + trifluralin fb Atlantis (+ Biopower)	4.0 l/ha + 2.3 l/ha fb 0.4kg/ha	Pre-em Pre-em 2-3 leaf (weed)	flufenacet + pendimethalin trifluralin mesosulfuron-methyl + iodosulfuron-methyl-sodium	60 g/l + 300 g/l 480 g/l 30 g/l + 6 g/l	240 g + 1200 g 1104 g 12 g + 2.4 g
5	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
6	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
7	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	400 g/l + 100 g/l	240 g + 60 g
8	Crystal + Defy	4.0 l/ha + 5.0 l/ha	Pre-em Pre-em	flufenacet + pendimethalin prosulfocarb	60 g/l + 300 g/l 800 g/l	240 g + 1200 g 4000 g
9.	Defy + Hurricane	5.0 l/ha + 0.12 l/ha	Pre-em	prosulfocarb + diflufenican	800 g/l + 500 g/l	4000 g + 60 g
10	Liberator + Hurricane	0.6 l/ha + 0.12 l/ha	Pre-em	flufenacet + diflufenican + diflufenican	400 g/l + 100 g/l + 500 g/l	240 g + 60 g + 60 g
11	Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em Peri-em	flufenacet + diflufenican prosulfocarb	400 g/l + 100 g/l 800 g/l	240 g + 60 g 4000 g
12	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
13	Hurricane	0.25 l/ha	Pre-em	diflufenican	500 g/l	125 g
14	pendimethalin	1200 g ai/ha	Pre-em	pendimethalin	-	1200 g
15	Skirmish	1.0 l/ha	Pre-em	isoxaben + terbuthylazine	75 g/l + 420 g/l	75 g + 420 g
16	Artist	1.0 kg/ha	Pre-em	flufenacet + metribuzin	24% w/w + 17.5% w/w	240g + 175g
17	Crystal	4.0 l/ha	Peri-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
18	Defy	5.0 l/ha	Peri-em	prosulfocarb	800 g/l	4000 g
19	Graduate	0.625 l/ha	1 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
20	chlorotoluron + Hurricane	3500g + 0.12 l/ha	1 leaf 1 leaf	chlorotoluron diflufenican	 500 g/l	3500g 60 g
21	Guillotine	0.1 l/ha	1 leaf	flumioxazine	300 g/l	30 g
22	Liberator fb Crystal	0.6 l/ha fb 4 l/ha	Pre-em Peri-em	flufenacet + diflufenican flufenacet + pendimethalin	400 g/l + 100 g/l 60 g/l + 300 g/l	240 g + 60 g 240 g + 1200 g
23	Liberator fb Crystal + pendimethalin	0.6 l/ha fb 2.0 l/ha + 1.8 l/ha	Pre-em Peri-em	flufenacet + diflufenican prosulfocarb + pendimethalin	400 g/l + 100 g/l 800 g/l	240 g + 60 g 4000 g
24	Crystal fb Defy	4.0 l/ha fb 5.0 l/ha	Pre-em Peri-em	flufenacet + pendimethalin prosulfocarb	60 g/l + 300 g/l 800 g/l	240 g + 1200 g 4000 g
25	Crystal fb Graduate	4.0 l/ha fb 0.625 l/ha	Pre-em 1 leaf	flufenacet + pendimethalin flurtamone + diflufenican	60 g/l + 300 g/l 400 g/l + 80 g/l	240 g + 1200 g 250 g + 50 g
26	Crystal + Defy fb Graduate	4.0 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em Pre-em 1 leaf	flufenacet + pendimethalin prosulfocarb flurtamone + diflufenican	60 g/l + 300 g/l 800 g/l 400 g/l + 80 g/l	240 g + 1200 g 4000 g 250 g + 50 g
27	Crystal + Defy fb Graduate fb Guillotine	4.0 l/ha + 5.0 l/ha fb 0.625 l/ha fb 0.1 l/ha	Pre-em Pre-em 1 leaf 2-3 leaf	flufenacet + pendimethalin prosulfocarb flurtamone + diflufenican flumioxazine	60 g/l + 300 g/l 800 g/l 400 g/l + 80 g/l 300 g/l	240 g + 1200 g 4000 g 250 g + 50 g 30 g

Table A7. Treatment list for experiments addressing black-grass in winter oilseed rape in the 2008/09 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated	-	-			
2.	Untreated	-	-			
3.	Butisan S + trifluralin fb Kerb Flo	1.5 l/ha + 2.3 l/ha fb 2.1 l/ha	Pre-em Pre-em Mid Nov	metazachlor trifluralin propyzamide	500 g/l 480 g/l 400 g/l	750 g 1104 g 840 g
4.	Butisan S	1.5 l/ha	Pre-em	metazachlor	500 g/l	750 g
5.	Butisan S	2.5 l/ha	Pre-em	metazachlor	500 g/l	1250 g
6.	Centium	0.33 l/ha	Pre-em	clomazone	360 g/l	118.8 g
7.	Devrinol	2.8 l/ha	Pre-em	napropamide	450 g/l	1260 g
8.	Butisan S + Devrinol	1.5 l/ha + 2.8 l/ha	Pre-em Pre-em	metazachlor napropamide	500 g/l 450 g/l	750 g 1260 g
9.	Butisan S + Centium	1.5 + 0.33	Pre-em Pre-em	metazachlor clomazone	500 g/l 360 g/l	750 g 118.8 g
10.	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
11.	Butisan S fb Laser (+ adjuvant)	1.5 l/ha fb 0.8 l/ha	Pre-em Mid Oct	metazachlor cycloxydim	500 g/l 200 g/l	750 g 160 g
12.	Butisan S fb Kerb Flo	1.5 l/ha fb 1.7 l/ha	Pre-em Mid Nov	metazachlor propyzamide	500 g/l 400 g/l	750 g 680 g
13.	Kerb Flo	2.1 l/ha	Mid Oct	propyzamide	400 g/l	840 g
14.	Kerb Flo	2.1 l/ha	Mid Nov	propyzamide	400 g/l	840 g
15.	Kerb Flo	2.1 l/ha	Late Jan.	propyzamide	400 g/l	840 g
16.	Kerb Flo	1.7 l/ha	Mid Nov.	propyzamide	400 g/l	680 g
17.	Kerb Flo	1.4 l/ha	Mid Nov	propyzamide	400 g/l	560 g
18.	Kerb Flo + Laser (+ adjuvant)	1.7 l/ha + 0.8 l/ha	Mid Nov Mid Nov	propyzamide cycloxydim	400 g/l 200 g/l	680 g 160 g
19.	Laser (+ adjuvant) fb Kerb Flo	0.8 l/ha fb 1.7 l/ha	Mid Oct Mid Nov	cycloxydim propyzamide	200 g/l 400 g/l	160 g 680 g
20.	Kerb Flo fb Kerb Flo	1.05 l/ha fb 1.05 l/ha	Mid Oct Mid Nov.	propyzamide propyzamide	400 g/l 400 g/l	420 g 420 g
21.	Crawler	3.5 kg/ha	Mid Oct	carbetamide	60 % w/w	2100 g
22.	Crawler	3.5 kg/ha	Mid Nov.	carbetamide	60 % w/w	2100 g
23.	Crawler + Laser (+ adjuvant)	3.5 kg/ha + 0.8 l/ha	Mid Nov Mid Nov	carbetamide cycloxydim	60 % w/w 200 g/l	2100 g 160 g
24.	Crawler fb Kerb Flo	1.75 kg/ha fb 1.05 l/ha	Mid Oct Mid-Nov	carbetamide propyzamide	60 % w/w 400 g/l	1050 g 420 g

Table A8. Treatment list for experiments addressing annual meadow grass in winter wheat in the 2008/09 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated	-	-			
2.	Untreated	-	-			
3.	isoproturon	1,000 g ai/ha	1-2 leaf	isoproturon	-	1000 g
4.	chlorotoluron	1,500 g ai/ha	1-2 leaf	chlorotoluron	-	1500 g
5.	Crystal	1.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	60 g + 300 g
6.	Crystal	2.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	120 g + 600 g
7.	Defy	1.5 l/ha	Pre-em	prosulfocarb	800 g/l	1200 g
8	Defy	3.0 l/ha	Pre-em	prosulfocarb	800 g/l	2400 g
9	Defy	3.0 l/ha	1-2 leaf	prosulfocarb	800 g/l	9 g + 45 g
10.	Liberator + Hurricane	0.15 l/ha + 0.03 l/ha	Pre-em Pre-em	flufenacet + diflufenican diflufenican	60 g/l + 300 g/l 500 g/l	9 g + 45 g 15 g
11	Liberator + Hurricane	0.3 l/ha + 0.06 l/ha	Pre-em Pre-em	flufenacet + diflufenican diflufenican	60 g/l + 300 g/l 500 g/l	18 g + 90 g 30 g
12	Flight	2.0 l/ha	Pre-em	pendimethalin + picolinafen	330 g/l + 7.5 g/l	660 g + 15 g
13	Bacara	0.6 l/ha	Pre-em	diflufenican + flurtamone	100 g/l + 250 g/l	60 g + 150 g
14	Lexus	20 g/ha	Pre-em	flupyrsulfuron-methyl	50% w/w	10 g
15	Defy + Hurricane	1.5 l/ha + 0.12 l/ha	Pre-em Pre-em	prosulfocarb diflufenican	800 g/l + 500g/l	1200 g + 60 g
16	Hurricane	0.12 l/ha	Pre-em	diflufenican	500 g/l	60 g
17	Guillotine	0.1 l/ha	1-2 leaf	flumioxazine	300 g/l	30 g
18	flufenacet	120 g ai/ha	Pre-em	flufenacet	-	120 g
19	flufenacet	120 g ai/ha	1-2 leaf	flufenacet	-	120 g
20..	pendimethalin	600 g ai/ha	Pre-em	pendimethalin	-	600 g
21	pendimethalin + Lexus	600 g ai/ha + 20 g/ha	Pre-em Pre-em	pendimethalin flupyrsulfuron-methyl	- 50% w/w	600 g 10 g
22	pendimethalin	1200 g ai/ha	Pre-em	pendimethalin	-	1200 g
23	Defy + Lexus	3.0 l/ha + 20 g/ha	Pre-em Pre-em	prosulfocarb flupyrsulfuron-methyl	800 g/l 50% w/w	2400 g 10 g
24	Othello (+ Biopower)	0.5 l/ha	2-3 leaf (weed)	diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 g/l + 2.5 g/l + 7.5 g/l	25 g + 1.25 g + 3.75 g

Table A9. Treatment list for experiments addressing barren brome in winter wheat in the 2008/09 season.

	Treatment	*Dose (l/ha)*	*Timing*	*active ingredient*	*concentration*	*dose of active per ha*
1.	Untreated	-	-			
2.	Untreated	-	-			
3	Liberator fb Atlantis (+Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em 2-3 leaf (weed)	flufenacet + diflufenican mesosulfuron-methyl + iodosulfuron-methyl-sodium	60 g/l + 300 g/l 30 g/l + 6 g/l	36 g + 180 g 12 g + 2.4 g
4	Liberator fb Monitor	0.6 l/ha fb 25 g/ha	Pre-em Spring growth	flufenacet + diflufenican sulfosulfuron	60 g/l + 300 g/l 80% w/w	36 g + 180 g 20 g
5	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
6	Defy	5 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
7	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	60 g/l + 300 g/l	36 g + 180 g
8	Avadex Excel	15 kg/ha	Pre-em	tri-allate	15% w/w	2250 g
9	Defy + Hurricane	5 l/ha + 0.12 l/ha	Pre-em Pre-em	prosulfocarb diflufenican	800 g/l 500 g/l	4000 g 60 g
10	Hurricane	0.12 l/ha	Pre-em	diflufenican	500 g/l	60 g
11	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
12	Liberator + Avadex Excel	0.6 l/ha 15 kg/ha	Pre-em Pre-em	flufenacet + diflufenican tri-allate	60 g/l + 300 g/l 15% w/w	36 g + 180 g 2250 g
13	Liberator fb chlorotoluron	0.6 l/ha fb 3,500 g ai/ha	Pre-em 1-2 leaf	flufenacet + diflufenican chlorotoluron	60 g/l + 300 g/l -	36 g + 180 g 3500 g
14.	Avadex Excel + Liberator fb chlorotoluron	15 kg/ha + 0.6 l/ha fb 3,500 g ai/ha	Pre-em Pre-em 1-2 leaf	tri-allate flufenacet + diflufenican chlorotoluron	15% w/w 60 g/l + 300 g/l -	2250 g 36 g + 180 g 3500 g
15.	isoproturon	2,500 g ai/ha	1-2 leaf	isoproturon	-	2500 g
16.	chlorotoluron	3,500 g ai/ha	1-2 leaf	chlorotoluron	-	3500 g
17.	Atlantis (+ Biopower)	0.4 kg/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium	30 g/l + 6 g/l	12 g + 2.4 g
18.	Avadex Excel fb Atlantis (+Biopower)	15kg/ha fb 0.4 kg/ha	Pre-em 2-3 leaf (weed)	tri-allate mesosulfuron-methyl + iodosulfuron-methyl-sodium	15% w/w 30 g/l + 6 g/l	2250 g 12 g + 2.4 g
19.	Atlantis (+ Biopower) + Hurricane	0.4 kg/ha + 0.12 l/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium diflufenican	30 g/l + 6 g/l 500 g/l	12 g + 2.4 g 60 g
20.	Othello (+ Biopower)	1.0 l/ha	2-3 leaf (weed)	diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 g/l + 2.5 g/l + 7.5 g/l	50 g + 2.5 g + 7.5 g
21.	HGCA2 (+ adjuvant)	250 g/ha	2-3 leaf (weed) 2-3 leaf (weed)	pyroxsulam	-	-
22.	HGCA2 (+ adjuvant)	250 g/ha	spring growth spring growth	pyroxsulam	-	-
23.	Monitor	25 g/ha	spring growth	sulfosulfuron	80% w/w	20 g
24.	Pacifica (+ BioPower)	0.5 kg/ha	spring growth	iodosulfuron-methyl-sodium + mesosulfuron-methyl	1.0% w/w + 3.0% w/w	5 g + 15 g

Table A10. Treatment list for experiments addressing black-grass in winter wheat in the 2009/10 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated					
2.	Untreated					
3	Liberator + Defy fb Atlantis (+ Biopower)	0.6 + 2.0 l/ha fb 0.4kg/ha	Pre-em Pre-em 2-3 leaf (weed)	flufenacet + diflufenican prosulfocarb mesosulfuron-methyl + iodosulfuron-methyl-sodium	400 g/l + 100 g/l 800 g/l 30 g/l + 6 g/l	240 g + 60 g 1600 g 12 g + 2.4 g
4	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
5	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	400 g/l + 100 g/l	240 g + 60 g
6	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
7	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
8	Skirmish	1.0 l/ha	Pre-em	isoxaben + terbuthylazine	75 g/l + 420 g/l	75g + 420g
9	Artist	1.0 kg/ha	Pre-em	flufenacet + metribuzin	24% w/w + 17.5% w/w	240g + 175g
10	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
11	Defy + Hurricane	5.0 l/ha + 0.12 l/ha	Pre-em Pre-em	prosulfocarb diflufenican	800 g/l 500 g/l	4000 g 60 g
12	Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em Peri-em	flufenacet + diflufenican prosulfocarb	400 g/l + 100 g/l 800 g/l	240 g + 60 g 4000 g
13	Defy + Avadex Excel	5.0 l/ha 15 kg/ha	Pre-em Pre-em	prosulfocarb tri-allate	800 g/l 50% w/w	4000 g 2250 g
14	chlorotoluron + Hurricane	2000g + 0.12 l/ha	Pre-em Pre-em	chlorotoluron diflufenican	500g/l 500 g/l	2000g 60 g
15	Untreated					
16	Reglone	2.0 l/ha	Peri-em	diquat	200 g/l	400 g
17	chlorotoluron + Hurricane	2000g + 0.12 l/ha	Peri-em Peri-em	chlorotoluron diflufenican	500g/l 500 g/l	2000g 60 g
18	Topik	0.25 l/ha	1 leaf	clodinafop-propargyl	240 g/l	60 g
19	chlorotoluron + Hurricane	2000g + 0.12 l/ha	1 leaf 1 leaf	chlorotoluron diflufenican	500g/l 500 g/l	2000g 60 g
20	Graduate	0.625 l/ha	1 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
21	Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em 1 leaf	flufenacet + diflufenican flufenacet + diflufenican	400 g/l + 100 g/l 400 g/l + 200 g/l	240 g + 60 g 120 g + 60 g
22	Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha 240 g ai/ha	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican flufenacet + diflufenican flufenacet	400 g/l + 100 g/l 400 g/l + 200 g/l -	240 g + 60 g 120 g + 60 g 120 g

23	Liberator fb Firebird + chlorotoluron	0.6 l/ha fb 0.3 l/ha 2000g	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican flufenacet + diflufenican chlorotoluron	400 g/l + 100 g/l 400 g/l + 200 g/l 500g/l	240 g + 60 g 120 g + 60 g 2000g
24	Liberator fb chlorotoluron + Hurricane	0.6 l/ha 2000g + 0.12 l/ha	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican chlorotoluron diflufenican	400 g/l + 100 g/l 500g/l 500 g/l	240 g + 60 g 2000g 60 g
25	Defy + Avadex Excel	5.0 l/ha 15 kg/ha	Pre-em Pre-em	prosulfocarb tri-allate	800 g/l 50% w/w	4000 g 2250 g
	fb chlorotoluron + Hurricane	2000g + 0.12 l/ha	1 leaf 1 leaf	chlorotoluron diflufenican	500g/l 500 g/l	2000g 60 g
26	Defy + Avadex Excel Graduate	5.0 l/ha 15 kg/ha 0.625 l/ha	Pre-em Pre-em 1 leaf	prosulfocarb tri-allate flurtamone + diflufenican	800 g/l 50% w/w 400 g/l + 80 g/l	4000 g 2250 g 250 g + 50 g
27	Liberator + Defy Graduate	0.6 l/ha + 5.0 l/ha 0.625 l/ha	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican prosulfocarb flurtamone + diflufenican	400 g/l + 100 g/l 800 g/l 400 g/l + 80 g/l	240 g + 60 g 4000 g 250 g + 50 g

Table A11. Treatment list for experiments addressing black-grass in winter oilseed rape in the 2009/10 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1.	Untreated	-	-			
2.	Untreated	-	-			
3.	Butisan S fb Kerb Flo	1.5 l/ha fb 2.1 l/ha	Pre-em Mid Nov	metazachlor propyzamide	500 g/l 400 g/l	750 g 840 g
4.	Butisan S	1.5 l/ha	Pre-em	metazachlor	500 g/l	750 g
5.	Devrinol	2.8 l/ha	Pre-em	napropamide	450 g/l	1260 g
6.	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
7.	Crawler	2.3 kg/ha	Pre-em	carbetamide	60 % w/w	1380 g
8.	Teridox	2.0 l/ha	Pre-em	dimethachlor	500.000 g/l	1000 g
9.	Kerb Flo	1.4 l/ha	Mid Nov	propyzamide	400 g/l	560 g
10.	Kerb Flo	2.1 l/ha	Mid Nov.	propyzamide	400 g/l	840 g
11.	Crawler	2.3 kg/ha	Mid Nov.	carbetamide	60 % w/w	1380 g
12.	Crawler	3.5 kg/ha	Mid Nov.	carbetamide	60 % w/w	2100 g
13.	Kerb Flo + Crawler	1.4 l/ha 2.3 kg/ha	Mid Nov Mid Nov.	propyzamide carbetamide	400 g/l 60 % w/w	560 g 1380 g
14.	Kerb Flo + Crawler + Laser (+adjuvant)	1.4 l/ha 2.3 kg/ha + 0.8 l/ha	Mid Nov Mid Nov. Mid Nov.	propyzamide carbetamide cycloxydim	400 g/l 60 % w/w 200 g/l	560 g 1380 g 160 g
15.	Butisan S + Centium	1.5 + 0.33	Pre-em Pre-em	metazachlor clomazone	500 g/l 360 g/l	750 g 118.8 g
16.	Butisan S + Devrinol	1.5 l/ha + 2.8 l/ha	Pre-em Pre-em	metazachlor napropamide	500 g/l 450 g/l	750 g 1260 g
17.	Devrinol + Centium	2.8 l/ha + 0.33	Pre-em Pre-em	napropamide clomazone	450 g/l 360 g/l	1260 g 118.8 g
18.	Avadex Excel + Devrinol	15 kg/ha + 2.8 l/ha	Pre-em Pre-em	tri-allate napropamide	50% w/w 450 g/l	2250 g 1260 g
19.	Avadex Excel + Devrinol + Centium	15 kg/ha + 2.8 l/ha + 0.33	Pre-em Pre-em Pre-em	tri-allate napropamide clomazone	50% w/w 450 g/l 360 g/l	2250 g 1260 g 118.8 g
20.	Butisan S	1.5 l/ha	2 leaf	metazachlor	500 g/l	750 g
21.	flufenacet	240 g ai/ha	2 leaf	flufenacet	-	240 g
22.	ethofumesate	1000 g ai/ha	2 leaf	ethofumesate	500 g/l	1000 g
23.	Skirmish	1.0 l/ha	2 leaf	isoxaben + terbuthylazine	75 g/l + 420 g/l	75g + 420g
24.	Reglone	2.0 l/ha	2 leaf	diquat	200 g/l	400 g

Table A12. Treatment list for experiments addressing barren brome in winter wheat in the 2009/10 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1	Untreated	-	-			
2	Untreated	-	-			
3	Liberator fb Atlantis (+ Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em 2-3 leaf (weed)	flufenacet + diflufenican mesosulfuron-methyl + iodosulfuron-methyl-sodium	60 g/l + 300 g/l 30 g/l + 6 g/l	36 g + 180 g 12 g + 2.4 g
4	Defy	5 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
5	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	60 g/l + 300 g/l	36 g + 180 g
6	Avadex Excel	15 kg/ha	Pre-em	tri-allate	15% w/w	2250 g
7	Defy + Liberator	5 l/ha 0.6 l/ha	Pre-em Pre-em	prosulfocarb flufenacet + diflufenican	800 g/l 60 g/l + 300 g/l	4000 g 36 g + 180 g
8	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
9	Skirmish	1.0 l/ha	Pre-em	isoxaben + terbuthylazine	75 g/l + 420 g/l	75g + 420g
10	Artist	1.0 l/ha	Pre-em	flufenacet + metribuzin	24:17.5 % w/w	240 g + 175 g
11	chlorotoluron	2000 g ai/ha	1-2 leaf	chlorotoluron	500 g/l	2000 g
12	Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em 1-2 leaf	flufenacet + diflufenican flufenacet + diflufenican	400 g/l + 100 g/l 400 g/l + 200 g/l	240 g + 60 g 120 g + 60 g
13	Liberator fb chlorotoluron	0.6 l/ha fb 2000 g ai/ha	Pre-em 1-2 leaf	flufenacet + diflufenican chlorotoluron	60 g/l + 300 g/l 500 g/l	36 g + 180 g 2000 g
14	Avadex Excel + Liberator fb chlorotoluron	15 kg/ha 0.6 l/ha fb 2000 g ai/ha	Pre-em Pre-em 1-2 leaf	tri-allate flufenacet + diflufenican chlorotoluron	15% w/w 60 g/l + 300 g/l 500 g/l	2250 g 36 g + 180 g 2000 g
15	Avadex Excel + Defy fb chlorotoluron	15 kg/ha 5 l/ha fb 2000 g ai/ha	Pre-em Pre-em 1-2 leaf	tri-allate prosulfocarb chlorotoluron	15% w/w 800 g/l 500 g/l	2250 g 4000 g 2000 g
16	Atlantis (+ Biopower)	0.4 kg/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium	30 g/l + 6 g/l	12 g + 2.4 g
17	Atlantis (+ Biopower) + Hurricane	0.4 kg/ha + 0.12 l/ha	2-3 leaf (weed) 2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium diflufenican	30 g/l + 6 g/l 500 g/l	12 g + 2.4 g 60 g
18	Broadway Star	0.265 l/ha	2-3 leaf (weed)	florasulam + pyroxsulam	1.42:7.08 % w/w	3.8 g + 18.8 g
19	Othello (+ Biopower)	1.0 l/ha	2-3 leaf (weed)	diflufenican + iodosulfuron-methyl-sodium + mesosulfuron-methyl	50 g/l + 2.5 g/l + 7.5 g/l	50 g + 2.5 g + 7.5 g
20	Avadex Excel fb Atlantis (+ Biopower)	15kg/ha fb 0.4 kg/ha	Pre-em 2-3 leaf (weed)	tri-allate mesosulfuron-methyl + iodosulfuron-methyl-sodium	15% w/w 30 g/l + 6 g/l	2250 g 12 g + 2.4 g
21	Avadex Excel + Liberator fb Atlantis (+ Biopower)	15kg/ha 0.6 l/ha fb 0.4 kg/ha	Pre-em Pre-em 2-3 leaf (weed)	tri-allate flufenacet + diflufenican mesosulfuron-methyl + iodosulfuron-methyl-sodium	15% w/w 60 g/l + 300 g/l 30 g/l + 6 g/l	2250 g 36 g + 180 g 12 g + 2.4 g
22	Liberator fb Broadway Star	0.6 l/ha fb 0.265 l/ha	Pre-em 2-3 leaf (weed)	flufenacet + diflufenican florasulam + pyroxsulam	60 g/l + 300 g/l 1.42:7.08 % w/w	36 g + 180 g 3.8 g + 18.8 g
23	Broadway Star	0.265 l/ha	Spring growth	florasulam + pyroxsulam	1.42:7.08 % w/w	3.8 g + 18.8 g
24	Pacifica (+ BioPower)	0.5 kg/ha	Spring growth	iodosulfuron-methyl-sodium + mesosulfuron-methyl	1.0% w/w + 3.0% w/w	5 g + 15 g

Table A13. Treatment list for experiments addressing black-grass in winter wheat in the 2010/11 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1	Untreated					
2	Untreated					
3	Liberator + Defy fb Atlantis (+ Biopower)	0.6 + 2.0 l/ha fb 0.4kg/ha	Pre-em Pre-em 2-3 leaf (weed)	flufenacet + diflufenican prosulfocarb mesosulfuron-methyl + iodosulfuron-methyl-sodium	400 g/l + 100 g/l 800 g/l 30 g/l + 6 g/l	240 g + 60 g 1600 g 12 g + 2.4 g
4	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
5	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	400 g/l + 100 g/l	240 g + 60 g
6	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
7	flufenacet	240 g ai/ha	Pre-em	flufenacet	-	240 g
8	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
9	HGCA1	- l/ha	Pre-em	-	-	-
10	Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em Peri-em	flufenacet + diflufenican prosulfocarb	400 g/l + 100 g/l 800 g/l	240 g + 60 g 4000 g
11	Defy + HGCA1	5.0 l/ha + - l/ha	Pre-em Pre-em	prosulfocarb -	800 g/l -	4000 g -
12	chlorotoluron	2000g	1 leaf	chlorotoluron	500g/l	2000 g
13	chlorotoluron	1500g	1 leaf	chlorotoluron	500g/l	1500 g
14	Untreated					
15	Topik	0.25 l/ga	1 leaf	clodinafop-propargyl	240 g/l	60 g
16	Graduate	0.625 l/ha	1 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
17	Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em 1 leaf	flufenacet + diflufenican flufenacet + diflufenican	400 g/l + 100 g/l 400 g/l + 200 g/l	240 g + 60 g 120 g + 60 g
18	Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican flufenacet + diflufenican flufenacet	400 g/l + 100 g/l 400 g/l + 200 g/l -	240 g + 60 g 120 g + 60 g 120 g
19	Liberator fb Firebird + chlorotoluron	0.6 l/ha fb 0.3 l/ha + 1500g	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican flufenacet + diflufenican chlorotoluron	400 g/l + 100 g/l 400 g/l + 200 g/l 500g/l	240 g + 60 g 120 g + 60 g 1500g
20	Defy + HGCA1 fb chlorotoluron + Hurricane	5.0 l/ha + - l/ha fb 1500g + 0.12 l/ha	Pre-em Pre-em 1 leaf 1 leaf	prosulfocarb - chlorotoluron diflufenican	800 g/l - 500g/l 500 g/l	4000 g - 1500g 60 g
21	Defy + HGCA1	5.0 l/ha + - l/ha	Pre-em Pre-em	prosulfocarb -	800 g/l -	4000 g -

	fb Firebird	fb 0.3 l/ha	1 leaf	flufenacet + diflufenican	400 g/l + 200 g/l	120 g + 60 g
22	Defy + HGCA1 fb Liberator	5.0 l/ha + - l/ha fb 0.6 l/ha	Pre-em Pre-em 1 leaf	prosulfocarb - flufenacet + diflufenican	800 g/l - 400 g/l + 100 g/l	4000 g - 240 g + 60 g
23	Defy + HGCA1 fb Graduate	5.0 l/ha + - l/ha fb 0.625 l/ha	Pre-em Pre-em 1 lea	prosulfocarb - flurtamone + diflufenican	800 g/l - 400 g/l + 80 g/l	4000 g - 250 g + 50 g
24	Liberator + Defy fb Graduate	0.6 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican prosulfocarb flurtamone + diflufenican	400 g/l + 100 g/l 800 g/l 400 g/l + 80 g/l	240 g + 60 g 4000 g 250 g + 50 g

Table A14. Treatment list for experiments addressing black-grass in winter barley in the 2010/11 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1	Untreated					
2	Untreated					
3	Liberator + Defy fb Axial (+ Adigor) + Stomp 400	0.6 l/ha + 2.0 l/ha fb 0.45 l/ha + 3.0 l/ha	Pre-em Pre-em 2-3 leaf 2-3 leaf	flufenacet + diflufenican prosulfocarb pinoxaden pendimethalin	400 g/l + 100 g/l 800 g/l 100 g/l 400 g/l	240 g + 60 g 1600 g 45 g 1200 g
4	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
5	Defy	5.0 l/ha	1 leaf (crop)	prosulfocarb	800 g/l	4000 g
6	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	400 g/l + 100 g/l	240 g + 60 g
7	Crystal	4.0 l/ha	Pre-em	flufenacet + pendimethalin	60 g/l + 300 g/l	240 g + 1200 g
8	Artist	1.0 l/ha	Pre-em	flufenacet + metribuzin	24:17.5 % w/w	240 g + 175 g
9	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
10	HGCA1	- l/ha	Pre-em	-	-	-
11	Liberator + Defy	0.6 l/ha + 5.0 l/ha	Pre-em Peri-em	flufenacet + diflufenican prosulfocarb	400 g/l + 100 g/l 800 g/l	240 g + 60 g 4000 g
12	Defy + HGCA1	5.0 l/ha + - l/ha	Pre-em Pre-em	prosulfocarb -	800 g/l -	4000 g -
13	Lexus	20g/ha	Pre-em	flupyrsulfuron-methyl	50% w/w	10 g
14	chlorotoluron + Hurricane	1500g + 0.12 l/ha	1 leaf 1 leaf	chlorotoluron diflufenican	500g/l 500 g/l	1500g 60 g
15	Graduate	0.625 l/ha	1 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
16	Liberator fb chlorotoluron + Hurricane	0.6 l/ha fb 1500g + 0.12 l/ha	Pre-em 1 leaf 1 leaf	flufenacet + diflufenican chlorotoluron diflufenican	400 g/l + 100 g/l 500g/l 500 g/l	240 g + 60 g 1500g 60 g
17	Defy + HGCA1 fb chlorotoluron + Hurricane	5.0 l/ha + - l/ha fb 1500g + 0.12 l/ha	Pre-em Pre-em 1 leaf 1 leaf	prosulfocarb - chlorotoluron diflufenican	800 g/l - 500g/l 500 g/l	4000 g - 1500g 60 g
18	Liberator + HGCA1 fb Firebird	0.6 l/ha + - l/ha fb 0.3 l/ha	Pre-em Pre-em 1 leaf	flufenacet + diflufenican - flufenacet + diflufenican	400 g/l + 100 g/l - 400 g/l + 200 g/l	240 g + 60 g - 120 g + 60 g
19	Liberator + Defy fb Firebird	0.6 l/ha + 5.0 l/ha fb 0.3 l/ha	Pre-em Peri-em 1 leaf	flufenacet + diflufenican prosulfocarb flufenacet + diflufenican	400 g/l + 100 g/l 800 g/l 400 g/l + 200 g/l	240 g + 60 g 4000 g 120 g + 60 g
20	Liberator + Defy fb Graduate	0.6 l/ha + 5.0 l/ha fb 0.625 l/ha	Pre-em Peri-em 1 leaf	flufenacet + diflufenican prosulfocarb flurtamone + diflufenican	400 g/l + 100 g/l 800 g/l 400 g/l + 80 g/l	240 g + 60 g 4000 g 250 g + 50 g
21	Defy + HGCA1 fb Firebird	5.0 l/ha + - l/ha fb 0.3 l/ha	Pre-em Pre-em 1 leaf	prosulfocarb - flufenacet + diflufenican	800 g/l - 400 g/l + 200 g/l	4000 g - 120 g + 60 g

Table A15. Treatment list for experiments addressing black-grass in winter oilseed rape in the 2010/11 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***concentration***	***dose of active per ha***
1	Untreated	-	-			
2	Untreated	-	-			
3	Untreated	-	-			
4	Butisan S fb Kerb Flo	1.5 l/ha fb 2.1 l/ha	Pre-em Mid Nov	metazachlor propyzamide	500 g/l 400 g/l	750 g 840 g
5	Butisan S	1.5 l/ha	Pre-em	metazachlor	500 g/l	750 g
6	Devrinol	2.8 l/ha	Pre-em	napropamide	450 g/l	1260 g
7	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
8	HGCA1	- l/ha	Pre-em	-	-	-
9	Crawler	2.3 kg/ha	Pre-em	carbetamide	60 % w/w	1380 g
10	Kerb Flo	1.4 l/ha	Pre-em	propyzamide	400 g/l	560 g
11	Butisan S + HGCA1	1.5 l/ha + - l/ha	Pre-em Pre-em	metazachlor -	500 g/l -	750 g -
12	Crawler + HGCA1	2.3 kg/ha + - l/ha	Pre-em Pre-em	carbetamide -	60 % w/w -	1380 g -
13	Butisan S + Devrinol	1.5 l/ha + 2.8 l/ha	Pre-em Pre-em	metazachlor napropamide	500 g/l 450 g/l	750 g 1260 g
14	Devrinol + HGCA1	2.8 l/ha + - l/ha	Pre-em Pre-em	napropamide -	450 g/l -	1260 g -
15	Devrinol (incorporated) + HGCA1 (incorporated)	2.8 l/ha + - l/ha	Pre-em Pre-em	napropamide -	450 g/l -	1260 g -
16	Butisan S + HGCA1 + Devrinol	1.5 l/ha + - l/ha + 2.8 l/ha	Pre-em Pre-em Pre-em	metazachlor - napropamide	500 g/l - 450 g/l	750 g - 1260 g
17	Butisan S + Devrinol fb Kerb Flo	1.5 l/ha + 2.8 l/ha fb 1.4 l/ha	Pre-em Pre-em Mid Nov	metazachlor napropamide propyzamide	500 g/l 450 g/l 400 g/l	750 g 1260 g 560 g
18	Kerb Flo	1.4 l/ha	Mid Nov	propyzamide	400 g/l	560 g
19	Kerb Flo	2.1 l/ha	Mid Nov.	propyzamide	400 g/l	840 g
20	Crawler	2.3 kg/ha	Mid Nov.	carbetamide	60 % w/w	1380 g
21	Crawler	3.5 kg/ha	Mid Nov.	carbetamide	60 % w/w	2100 g
22	Kerb Flo + Crawler	1.4 l/ha + 2.3 kg/ha	Mid Nov Mid Nov.	propyzamide carbetamide	400 g/l 60 % w/w	560 g 1380 g
23	Butisan S	1.5 l/ha	2 leaf	metazachlor	500 g/l	750 g
24	flufenacet	240 g ai/ha	2 leaf	flufenacet	-	240 g

Table A16. Treatment list for experiments addressing barren brome in winter wheat in the 2010/11 season.

	Treatment	*Dose (l/ha)*	*Timing*	*active ingredient*	*product concentration*	*dose of active per ha*
1	Untreated	-	-			
2	Untreated	-	-			
3	Untreated	-	-			
4	Liberator fb Atlantis (+ Biopower)	0.6 l/ha fb 0.4 kg/ha	Pre-em 2-3 leaves (weed)	flufenacet + diflufenican mesosulfuron-methyl + iodosulfuron-methyl-sodium	60 g/l + 300 g/l 30 g/l + 6 g/l	36 g + 180 g 12 g + 2.4 g
5	Defy	5.0 l/ha	Pre-em	prosulfocarb	800 g/l	4000 g
6	Defy	5.0 l/ha	1-2 leaf	prosulfocarb	800 g/l	4000 g
7	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	60 g/l + 300 g/l	36 g + 180 g
8	HGCA1	- l/ha	Pre-em	-	-	-
9	Skirmish	1.0 l/ha	Pre-em	isoxaben + terbuthylazine	75 g/l + 420 g/l	75g + 420g
10	Artist	1.0 l/ha	Pre-em	flufenacet + metribuzin	24:17.5 % w/w	240 g + 175 g
11	chlorotoluron	2000 g ai/ha	1-2 leaf	chlorotoluron	500 g/l	2000 g
12	chlorotoluron	1500 g ai/ha	1-2 leaf	chlorotoluron	500 g/l	1500 g
13	Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em 1-2 leaf	flufenacet + diflufenican flufenacet + diflufenican	400 g/l + 100 g/l 400 g/l + 200 g/l	240 g + 60 g 120 g + 60 g
14	Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em 1 -2 leaf 1-2 leaf	flufenacet + diflufenican flufenacet + diflufenican flufenacet	400 g/l + 100 g/l 400 g/l + 200 g/l -	240 g + 60 g 120 g + 60 g 120 g
15	Liberator + HGCA1	0.6 l/ha + - l/ha	Pre-em Pre-em	flufenacet + diflufenican -	400 g/l + 100 g/l -	240 g + 60 g -
16	Liberator + HGCA1 fb chlorotoluron	0.6 l/ha + - l/ha fb 1500g	Pre-em Pre-em 1-2 leaf	flufenacet + diflufenican - chlorotoluron	400 g/l + 100 g/l - 500g/l	240 g + 60 g - 1500g
17	Atlantis (+ Biopower)	0.4 kg/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium	30 g/l + 6 g/l	12 g + 2.4 g
18	Horus (+ Biopower)	1.2 l/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl-sodium	10 g/l + 2 g/l	12 g + 2.4 g
19	Broadway Star	0.265 l/ha	2-3 leaf (weed)	florasulam + pyroxsulam	1.42:7.08 % w/w	3.8 g + 18.8 g
20	HGCA1 fb Atlantis (+ Biopower)	- l/ha fb 0.4 kg/ha	Pre-em fb 2-3 leaf (weed)	- mesosulfuron-methyl + iodosulfuron-methyl-sodium	- 30 g/l + 6 g/l	- 12 g + 2.4 g
21	HGCA1 + Liberator fb Atlantis (+ Biopower)	- l/ha + 0.6 l/ha fb 0.4 kg/ha	Pre-em Pre-em fb 2-3 leaf (weed)	- flufenacet + diflufenican mesosulfuron-methyl + iodosulfuron-methyl-sodium	- 60 g/l + 300 g/l 30 g/l + 6 g/l	- 36 g + 180 g 12 g + 2.4 g
22	Liberator fb Broadway Star	0.6 l/ha fb 0.265 l/ha	Pre-em 2-3 leaf (weed)	flufenacet + diflufenican florasulam + pyroxsulam	60 g/l + 300 g/l 1.42:7.08 % w/w	36 g + 180 g 3.8 g + 18.8 g
23	Broadway Star	0.265 l/ha	Spring growth	florasulam + pyroxsulam	1.42:7.08 % w/w	3.8 g + 18.8 g
24	Pacifica (+ BioPower)	0.5 kg/ha	Spring growth	iodosulfuron-methyl-sodium + mesosulfuron-methyl	1.0% w/w + 3.0% w/w	5 g + 15 g

Table A17. Treatment list for experiments addressing barren brome in winter barley in the 2010/11 season.

	Treatment	***Dose (l/ha)***	***Timing***	***active ingredient***	***product concentration***	***dose of active per ha***
1	Untreated					
2	Untreated					
3	Untreated					
4	Liberator	0.6 l/ha	Pre-em	flufenacet + diflufenican	60 g/l + 300 g/l	36 g + 180 g
5	Avadex Excel	15 kg/ha	Pre-em	tri-allate	50% w/w	2250 g
6	HGCA1	- l/ha	Pre-em	-	-	-
7	HGCA1 (incorporated)	- l/ha	Pre-em	-	-	-
8	Liberator + HGCA1	0.6 l/ha + - l/ha	Pre-em Pre-em	flufenacet + diflufenican -	400 g/l + 100 g/l -	240 g + 60 g -
9	Firebird	0.3 l/ha	1 -2 leaf	flufenacet + diflufenican	400 g/l + 200 g/l	120 g + 60 g
10	chlorotoluron	1500 g ai/ha	1-2 leaf	chlorotoluron	500 g/l	1500 g
11	Graduate	0.625 l/ha	1-2 leaf	flurtamone + diflufenican	400 g/l + 80 g/l	250 g + 50 g
12	Liberator fb Firebird	0.6 l/ha fb 0.3 l/ha	Pre-em 1-2 leaf	flufenacet + diflufenican flufenacet + diflufenican	400 g/l + 100 g/l 400 g/l + 200 g/l	240 g + 60 g 120 g + 60 g
13	Liberator fb Firebird + flufenacet	0.6 l/ha fb 0.3 l/ha + 240 g ai/ha	Pre-em 1 -2 leaf 1-2 leaf	flufenacet + diflufenican flufenacet + diflufenican flufenacet	400 g/l + 100 g/l 400 g/l + 200 g/l -	240 g + 60 g 120 g + 60 g 120 g
14	Liberator fb chlorotoluron	0.6 l/ha fb 1500g	Pre-em 1-2 leaf	flufenacet + diflufenican chlorotoluron	400 g/l + 100 g/l 500g/l	240 g + 60 g 1500g
15	Liberator + HGCA1 fb chlorotoluron	0.6 l/ha + - l/ha fb 1500g	Pre-em Pre-em 1-2 leaf	flufenacet + diflufenican - chlorotoluron	400 g/l + 100 g/l - 500g/l	240 g + 60 g - 1500g
16	Atlantis (+ Biopower)	0.4 kg/ha	2-3 leaf (weed)	mesosulfuron-methyl + iodosulfuron-methyl- sodium	30 g/l + 6 g/l	12 g + 2.4 g
17	Liberator + HGCA1 fb Firebird	0.6 l/ha + - l/ha fb 0.3 l/ha	Pre-em Pre-em 1 -2 leaf	flufenacet + diflufenican - flufenacet + diflufenican	400 g/l + 100 g/l - 400 g/l + 200 g/l	240 g + 60 g - 120 g + 60 g
18	Liberator + HGCA1 fb Firebird + chlorotoluron	0.6 l/ha + - l/ha fb 0.3 l/ha + 1500g	Pre-em Pre-em 1 -2 leaf 1-2 leaf	flufenacet + diflufenican - flufenacet + diflufenican chlorotoluron	400 g/l + 100 g/l - 400 g/l + 200 g/l 500g/l	240 g + 60 g - 120 g + 60 g 1500g

Appendix B – Application timings for all experiments

Application dates for field experiments in 2007/08

	Pre-em	Peri-em	1-2 leaf	2-3 leaf (weed)
Winter wheat black-grass				
Lincolnshire	04/10/2007	17/10/2007	25/10/2007	15/11/2007
Wiltshire	13/09/2007	03/10/2007	18/10/2007	29/10/2007
Suffolk	30/09/2007	08/10/2007	13/10/2007	05/11/2007

	Pre-em	1-2 leaf	2-3 leaf	Early spring
Winter wheat barren brome				
East Hermiston	10/10/2007	30/10/2007	30/10/2007	22/04/2008

	Pre-em	1-2 leaf	2-3 leaf
Winter wheat meadow grass			
Midlothian	02/09/2007	12/10/2007	12/11/2007

Application dates for field experiments in 2008/09

	Pre-em	Peri-em	1 leaf	2-3 leaf
Winter wheat black-grass				
Lincolnshire	13/10/2008	24/10/2008	29/10/2008	03/12/2008
Wiltshire	25/09/2008	17/10/2008	27/10/2008	06/11/2008

	Pre-em	1-2 leaf	2-3 leaf	Early spring
Winter wheat barren brome				
East Lothian	13/11/2008	18/02/2009	18/02/2009	14/05/2011

	Pre-em	1-2 leaf	2-3 leaf
Winter wheat meadow grass			
Norfolk	24/09/2008	13/10/2008	03/12/2008

	Pre-em	Oct	Nov	Jan
Oilseed Rape black-grass				
Norfolk	18/09/2008	13/10/2008	26/11/2008	-
Lincs (Gt Carlton)	20/09/2008	17/10/2008	26/11/2008	21/01/2009
Lincs (Orford)	29/09/2008	17/10/2008	26/11/2008	21/01/2009

Application dates for field experiments in 2009/10

Winter wheat black-grass	**Pre-em**	**Peri-em**	**1-2 leaf**	**2-3 leaf**
Lincolnshire	13/10/2009	30/10/2009	04/11/2009	09/12/2009
Bedfordshire	08/10/2009	06/11/2009	09/12/2009	08/04/2010

Winter wheat barren brome	**Pre-em**	**1-2 leaf**	**2-3 leaf**	**Early spring**
Norfolk	02/10/2009	22/10/2009	06/11/2009	16/03/2010
East Hermiston	18/10/2009	29/10/2009	02/12/2009	24/03/2010

Oilseed Rape black-grass	**Pre-em**	**Oct**	**Nov**	**Jan**
Lincolnshire	11/09/2009	22/10/2009	27/11/2009	18/01/2010

Application dates for field experiments in 2010/11

Winter wheat black-grass	**Pre-em**	**1-2 leaf**	**2-3 leaf**
Lincolnshire	14/10/2010	10/11/2010	18/01/2011
Hampshire	04/10/2010	15/10/2010	10/11/2010

Winter barley black-grass	**Pre-em**	**1-2 leaf**	**2-3 leaf**
Lincolnshire	15/10/2010	10/11/2010	18/01/2011
Norfolk	23/09/2010	25/10/2010	06/01/11

Winter wheat barren brome	**Pre-em**	**1-2 leaf**	**2-3 leaf**
Norfolk	13/10/2010	03/11/2010	24/01/2011
East Hermiston	14/10/2010	19/11/2010	29/03/2011

Winter wheat barren brome	**Pre-em**	**1-2 leaf**	**2-3 leaf**
Norfolk	23/09/2010	25/10/2010	06/01/2011
Edinburgh	28/09/2010	01/10/2010	19/01/2011
Aberdeen	16/10/2010	10/11/2010	15/12/2010

Oilseed Rape black-grass	**Pre-em**	**Oct**	**Nov**
Lincolnshire	16/09/2010	15/10/2010	15/11/2010
Wiltshire	28/08/2010	07/10/2010	16/11/2010