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Outdoor flowers: an evaluation of herbicides (project extension)

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Summary

Headline

Effective and crop safe herbicide treatments have been devised for alstromeria grown in Spanish tunnels, field grown dahlias and pot grown agapanthus providing much needed knowledge for these crops and so facilitating the production of these crops in the UK.

Background and expected deliverables

There are few on- or off-label approvals for using herbicides on a diverse range of ornamental flower crop. This is one of a number of knowledge-gaps that limits the expansion of cut-flower production in the UK. Earlier HDC-funded projects led to herbicide recommendations for sweet william, natural-season chrysanthemum, larkspur, china aster, cornflower, zinnia, larkspur, bupleurum, stock, snapdragon and delphinium. In this project herbicides were tested on three further flower crops – alstroemeria, dahlia and agapanthus.

The aim of the project was to find effective herbicides that were crop-safe on these species, so facilitating the production of these valuable cut-flowers.

Summary of the project and main conclusions

Alstroemeria (three cultivars grown in a Spanish tunnel), dahlia (two cultivars grown in the field) and agapanthus (two species grown as established pot-plants) were grown at Kirton in 2006 and the effects on crops and weeds of a number of likely herbicides were tested in replicated trials.

Alstroemeria
The treatments tested included pre-planting oxadiazon, pre-crop-emergence lenacil + linuron, chlorpropham + linuron, metribuzin, isoxaben + metazachlor and pendimethalin + metribuzin, early post-emergence lenacin + metamitron and isoxaben/terbutylazine + bentazone, early post-emergence metamitron followed by late post-emergence metamitron + asulam + mineral oil, and post-emergence bentazone and florasulam.

The results showed that a crop-safe herbicide programme for alstroemeria could be based on a combination of pre-emergence isoxaben + metazachlor and early post-emergence isoxaben/terbuthylazine + bentazone.

Dahlia
The treatments tested included pre-emergence oxadiazon, lenacil + linuron, chlorpropham + linuron, metribuzin, isoxaben + metazachlor and pendimethalin + metribuzin, early post-emergence lenacin + metamitron, and early post-emergence metamitron followed by metamitron + asulam + mineral oil.

From the results a pre-emergence application of lenacil + linuron or chlorpropham + linuron appeared to be the best option for dahlia, though others of the tested products might be acceptable as alternatives if slight crop damage or weed growth were acceptable. There may be scope for post-emergence testing of metamitron, alone or in combination with lenacil.

Agapanthus

The herbicides tested on pot-grown agapanthus were all crop-safe under the conditions used. They included pre-weed-emergence oxadiazon, propachlor and isoxaben + metazachlor, early post-weed-emergence lenacil + metamitron and isoxaben/terbutylazine + bentazone, early post-weed-emergence metamitron followed by late post-weed-emergence metamitron + asulam + mineral oil, and post-weed emergence bentazone and florasulam.

212H

The experimental material 212H was also tested on these crops. Its use proved effective in some cases, but, contrary to earlier expectations, the material is not now likely to become available to growers.

Financial benefits

The UK outdoor flower crop area is *ca.* 800 ha. With herbicides costing from about £200/ha and an application cost of about £15/ha, one herbicide application across the area would cost the industry around £175k *per annum*. With improved knowledge the cost of ineffective treatments can be saved, and finding effective materials will result in labour saving, through a reduction in hand weeding, and a better quality crop.

More importantly, adding to the technical knowledge on growing ornamental crops in the UK can be expected to increase the opportunities for growers to produce a wider range of high-quality flowers, further stimulating this expanding sector.

Action points for growers

The above findings are the result of single, one-year herbicide trials with two or three varieties of each crop. Therefore, although the results indicate some apparently crop-safe herbicides, herbicide timings and tank-mixes, any permissible but non-label use of a pesticide should be carried out with caution and will be at the grower's risk. Any new herbicide x crop combination should be used with caution and, until experience has been gained, on only small areas of crop.

Outdoor flowers: an evaluation of herbicides (project extension)

Introduction

The UK demand for cut-flowers is growing rapidly, and the production of flowers in the field or under low-cost tunnels provides a real opportunity for UK growers. However, the lack of technical information for the wide diversity of traditional and novel species being grown is a major factor limiting expansion of the sector. Discussions with flower growers invariably highlight a need for advice on herbicides. There are relatively few herbicide recommendations for flower crops, since agrochemical companies do not consider the relatively minor overall economic value of such crops sufficient to justify the high cost of the development and approval process. As a consequence, growers rely heavily on off-label usage and herbicide applications are often made on a 'd-i-y trial' basis.

In a previous HDC-funded project, BOF 51, a range of herbicides was tested successfully on several outdoor cut-flower crops - china aster, cornflower, zinnia, larkspur, nigella, bupleurum, snapdragon, stock and delphinium. This project extension of BOF 51 was set up in response to the requests of panel members for herbicide trials on further cut-flower species. The commercial objectives of the project extension were:

- To identify herbicides free of phytotoxic effects (including height and yield reduction) and otherwise suitable for use on *Alstroemeria*, *Agapanthus* and *Dahlia*
- To develop and publish herbicide recommendations for these species grown as cut-flowers.

As for the original project, successful completion of this work would produce a number of benefits for the industry:

- Labour savings and better cost-effectiveness (hand-weeding would not be necessary)
- Elimination of the risk of crop damage
- Environmental benefits and a more favourable pesticide audit, since any unnecessary or ineffective herbicide applications would be avoided
- Ability to produce a wider range of cut-flowers without taking risks with herbicides or having to carry out *ad hoc* tests.

The UK outdoor flower crop area is *ca.* 800 ha. With herbicides costing from about £200/ha and an application cost of about £15/ha, one herbicide application across the area would cost the industry around £175k *per annum*. With improved knowledge the cost of ineffective treatments can be saved and effective treatments will result in labour saving and a better quality crop.

Materials and methods

Plant material

Three cut-flower species were studied in this project: *Agapanthus* (Liliaceae), *Alstroemeria* (Amaryllidaceae) and *Dahlia* (Compositae). The choice and mix of cultivars used was made by HDC Panel members. All planting material was purchased from reputable Lincolnshire companies in May 2006 as follows:

- Alstroemeria: pot-grown rhizomes of three cultivars, 'Artica', 'Etna' and 'Laguna'. Pot size was 9cm. The amount of shoot growth varied between the cultivars, with 'Artica' least developed (buds not emerging) and 'Etna' most developed (shoots up to 15cm tall).
- Dahlia: dry tubers of two cultivars, 'Gallery Renoir' and 'Red Majorette'.
- Agapanthus: established pot-grown plants in growth. There were equal numbers of *Agapanthus umbellatus* in 2L-pots and *A. intermedius* in 1L-pots.

Trial site

All trials were carried out at The Kirton Research Centre (KRC) in a field with a medium silty marine alluvial soil and typical of the South Lincolnshire agricultural area where outdoor cut-flower crops are widely grown. Well prior to planting, the site was flat-lifted, ploughed and cultivated. To determine the fertiliser application needed, soil samples were taken in March 2006 from 0-30cm depth across the site after ploughing; standard agricultural soil analysis gave pH 7.3, P index 4, K index 2- and Mg index 3. The trial areas had been planted with various brassica crops in the previous year and the nitrate index was taken as 1. As a result of these indices no base fertiliser was applied.

Growing systems

Pot-grown alstroemeria were transplanted on 5 June 2006 into the soil of a Spanish tunnel (*ca*. 8m wide and 50m long) covered with a standard clear polythene film. Planting was such that the top of the original substrate surface was just covered by soil. Irrigation was applied through drip tape (T-tape). The crop was supported by chrysanthemum-type netting on posts.

Dahlia tubers were soaked in plain water for 24h before planting on 13 June 2006 in the open field with the tops just covered by soil. Irrigation and crop support was as for alstroemeria.

Agapanthus was kept as pot-grown plants and on 1 June 2006 were stood out on woven horticultural matting on the ground in a tunnel covered with a light bird-netting only. Irrigation was applied via overhead sprinklers. Once in full growth a half-strength tomato liquid feed was watered directly into the pots at intervals.

The trial areas were surrounded by electric and net fences to deter rabbits and other predators. Irrigation was applied as needed to obtain good herbicide action and good plant growth. In order to avoid spray drift, no herbicides were used on the pathways and trial surrounds.

The following pesticide applications were made to the trials in response to pests incidence:

- Methiocarb pellets against slugs on all three trials, 24 June 2006, repeated on agapanthus and dahlia 13 September 2006
- Pirimicarb spray against aphids on all three trials, 19 July 2006

Pesticide applications were made at standard rates and following the manufacturer's instructions.

Trial design

Alstroemeria and dahlia were grown in beds 1.2m-wide spaced at 1.8m centres. There were three beds across the alstroemeria tunnel and three beds across the outside dahlia area. Plots 2m-long and separated by 0.5m-long unplanted guard areas were marked along the beds and labelled. Alstroemeria plants were planted 12 per 2.4m^2 plot at a spacing of 0.4m between rows and 0.5m within rows. Dahlia tubers were planted 18 per 2.4m^2 plot at a spacing of 0.4m between rows and 0.33m within rows.

The pot-grown agapanthus were stood out in plots of an equivalent size and arrangement to those used for the preceding species. There were 9 pots (4 x 2L pots and 5 x 1L pots) per 2.4m^2 plot at a spacing of 0.4m between rows and 0.66m within rows.

Each species was tested in a randomised block design with three replicates. For alstroemeria one cultivar was used for each block. For dahlia one half (at random) of each plot was planted with 'Gallery Renoir' and the other with 'Red Majorette'. For agapanthus one half (at random) of each plot consisted of 2L-pots of *A. umbellatus* and the other half of 1L-pots of *A. intermedius*.

Herbicide treatments

Herbicide treatments were selected individually for the three species, extrapolating from some prior knowledge, anecdotal information and the findings of the earlier HDC-funded cut-flower herbicide project (BOF 51). The aim in the first year of the project extension was to test individual herbicide applications, obtaining robust data on the safety of herbicides for use in each species; this would allow full-season or on-going herbicide programmes to be tested at a later stage.

Treatments were timed for appropriate pre- and post- crop- and weed-emergence dates, with applications to emerged weeds generally aimed at the cotyledon to 1-true-leaf (1TL) stage. Details of the herbicide treatments used on each species are given in Tables 1-3. Throughout this report the addition symbol '+', rather than 'and', etc., is used to denote a tank-mix of the adjacent herbicides. Following the normal convention, two types of control plot were included: (1) no herbicides were applied but the plots were hand-weeded at about 2-weekly intervals, and (2) neither hand-weeding nor herbicides were used. This enables effects due to herbicides and those due to crop-weed competition to be distinguished.

Herbicides were applied using a precision sprayer ('Oxford') along the beds, with a medium spray quality for pre-emergence applications and a fine spray quality for post-emergence weeds. Herbicides were applied in 200L water per ha. The dates of and weather conditions for herbicide applications, and the growth stages (GS) of crops and weeds, are given in Tables 1-3.

Recently complied listings of the current approval status and weed susceptibilities of herbicides for ornamental crops are available in the reports of HDC-funded projects BOF 51, 52 and 58.

Weather data

Meteorological data were obtained from the KRC weather station, sited *ca.* 50m from the trial site. For each application date, the daily data relevant to spray applications are given in Tables 1-3, i.e. daily minimum and maximum screen temperatures, relative humidity (RH), precipitation, wind force and cloud amount.

Crop and weed assessments

- Crop and weed GS were recorded at the time of herbicide application.
- The following were recorded at weekly intervals for each plot from planting to cropping:
  - A crop tolerance score based on phytotoxicity symptoms and crop stand (see table below), with the type of damage
  - Weed levels as (1) the percentage of available ground covered by weeds and (2) an overall weed control score on a scale of 0 to 10 (0, no weed control, comparable with untreated plots), through 7, acceptable control, to 10, complete weed control, comparable with hand-weeded plots).
  - Weed species were recorded as present or absent. The ‘relative frequency’ of each weed species was expressed as the percentage of all plot assessments in which the species was present.
- The quality of marketable stems from successful herbicide-treated plots was checked visually against that of control (hand-weeded) plots.

Score	*Crop description*
0	Complete kill
1	80-95% damage (includes when most of crop is killed but some patches survive)
2	70-80% damage
3	60-70% damage
4	50-60% damage (includes serious yellowing, dwarfing, etc., but crop may grow out of damage)
5	40-50% damage
6	25-40% damage
7	20-25% damage (slight symptoms, unlikely to seriously affect yield, acceptable damage)
8	10-20% damage (slight damage)
9	5-10% damage (very slight damage)
10	no damage, as untreated plants

Data analysis

The results were expressed in Tables, etc., as the means of the three replicate plots. Generally the results of this type of trial are clear-cut, and no formal statistical analysis has been carried out.

Table 1. Herbicide treatments for alstroemeria in 2006, with GS for crops and weeds.

No.	*Herbicide active ingredient (product)*	*Rate of product (L or kg/ha)*
Controls		
1	untreated	-
2	hand-weeded	-
Pre-planting (2 June)		
3	oxadiazon (Ronstar)	4.0L
Pre-crop/weed-emergence (7 June) *Weather: temp. 11-23°C, RH 64%, rain 0mm, wind 3knots, cloud 3 oktas* *Crop GS: some emerged shoots in 'Etna' and 'Laguna'; weed GS: none visible*		
4	lenacil + linuron (Venzar Flowable + Alpha Linuron 50 SC)	2.0L +1.7L
5	chlorpropham + linuron (MSS 50CIPC + Alpha Linuron 50 SC)	6.0L+ 1.0L
6	metribuzin (Sencorex WG)	1.5kg
7	isoxaben + metazachlor (Flexidor + Butisan)	2.0L + 2.5L
8	pendimethalin + metribuzin (Stomp + Sencorex WG)	3.3L + 0.5kg
9	212 H (experimental product)	60g
Early post-emergence (23 June) *Weather: temp. 10-20°C, RH 60%, rain 1.0mm, wind 3 knots, cloud 8 oktas* *Crop GS: 'Artica' starting to emerge; weed GS: cotyledons – 1TL*		
10	lenacil + metamitron (Venzar + Goltix WG)	4.0L + 0.75L
11	isoxaben/terbuthylazine + bentazone (Skirmish + Basagran SL)	0.75L + 1.0L
12	212 H (experimental product)	60g
Early post-emergence (23 June) *Weather and GS: see above* ***and late post-emergence (10 July)*** *Weather: temp. 11-20°C, RH 68%, rain 0mm, wind 9 knots, cloud 0 oktas* *Crop GS: all cultivars growing well; weed GS: 4-6TL*		
13	metamitron (Goltix WG) *Followed by* metamitron + asulam + mineral oil (Goltix + Asulox + mineral oil)	2.5kg 2.5kg + 2.0L + 3.0L
Post-emergence (3 July) *Weather: temp. 16-28°C, RH 58%, rain 0.1mm, wind 5 knots, cloud 1okta* *Crop GS: all cultivars growing well, shoots 5-20cm; weed GS: 2-4TL*		
14	bentazone (Basagran SG)	1.65kg
15	florasulam (Boxer)	100ml

Table 2. Herbicide treatments for dahlia in 2006, with GS for crops and weeds.

No.	*Herbicide active ingredient (product)*	*Rate of product (L or kg/ha)*
Controls		
1	untreated	-
2	hand-weeded	-
Pre-crop/weed-emergence (14 June)		
Weather: temp. 13-18°C, RH 85%, rain 0mm, wind 4 knots, cloud 8 oktas		
Crop and weed GS: none visible		
3	oxadiazon (Ronstar)	4.0L
4	lenacil + linuron (Venzar Flowable + Alpha Linuron 50 SC)	2.0L +1.7L
5	chlorpropham + linuron (MSS 50CIPC + Alpha Linuron 50 SC)	6.0L+ 1.0L
6	metribuzin (Sencorex WG)	1.5kg
7	isoxaben + metazachlor (Flexidor 125 + Butisan)	2.0L + 2.5L
8	pendimethalin + metribuzin (Stomp + Sencorex WG)	3.3L + 0.5kg
9	212 H (experimental product)	60g
Early post-emergence (23 June)		
Weather: temp. 10-20°C, RH 60%, rain 1.0mm, wind 3 knots, cloud 8 oktas		
Crop GS: shoots just beginning to emerge; weed GS: cotyledons		
10	lenacil + metamitron (Venzar + Goltix WG)	4.0L + 0.75L
11	212 H (experimental product)	60g
Early post-emergence (23 June)		
Weather and GS: see above		
and late post-emergence (11 July)		
Weather: temp. 15-24°C, RH 67%, rain 0mm, wind 9 knots, cloud 3 oktas		
Crop GS: shoots about 20cm high; weed GS: 4-6 TL		
12	metamitron (Goltix WG)	2.5kg
	Followed by metamitron + asulam + mineral oil (Goltix + Asulox + mineral oil)	2.5kg + 2.0L + 3.0L

Table 3. Herbicide treatments for pot-grown agapanthus in 2006, with GS for crops and weeds.

No.	*Herbicide active ingredient (product)*	*Rate of product (L or kg/ha)*
Controls		
1	untreated	-
2	hand-weeded	-
After standing out, pre-weed-emergence (23 June)		
Weather: temp. 10-20°C, RH 60%, rain 1.0mm, wind 3 knots, cloud 8 oktas		
Crop GS: well grown, some plants in bud or flower; weed GS: none visible		
3	oxadiazon (Ronstar 20 granular)	200kg/ha
4	propachlor (Ramrod 20 granules)	34kg/ha
6	isoxaben + metazachlor (Flexidor 125 + Butisan)	1.0L + 2.5L
Early post-weed-emergence (10 August)		
Weather: temp. 10-20°C, RH 53%, rain 1.4mm, wind 5 knots, cloud 7 oktas		
Crop GS: some plants in flower; weed GS: none visible (spray applied to check for toxicity to crop)		
7	lenacil + metamitron (Venzar + Goltix WG)	4.0L + 0.75L
8	isoxaben/terbuthylazine + bentazone (Skirmish + Basagran SL)	0.75L + 1.0L
Early post-weed-emergence (10 August)		
Weather and GS: see above		
and late post-weed-emergence (13 September, 19°C, 89%RH)		
Weather: temp. 16-25°C, RH 83%, rain 5.3mm, wind 3 knots, cloud 5 oktas		
Crop GS: some plants in flower; weed GS: cotyledon – 2TL, numbers sparse (spray applied to check for toxicity to crop)		
9	metamitron (Goltix WG)	2.5kg
	Followed by metamitron + asulam + mineral oil (Goltix + Asulox + mineral oil)	2.5kg + 2.0L + 3.0L
Post-emergence (25 August)		
Weather: temp. 8-22°C, RH 72%, rain 0.5mm, wind 2 knots, cloud 1 okta		
Crop GS: some plants in flower; weed GS: cotyledon – 2TL, numbers sparse (spray applied to check for toxicity to crop)		
10	bentazone (Basagran SG)	1.65kg
11	florasulam (Boxer)	100ml

Results and discussion

Alstroemeria

Crop tolerance to treatments is shown for representative assessment dates in Figure 1. The crop tolerance score used runs from 0, representing a lethal effect of the herbicide on the alstroemeria crop, to 10, meaning the crop was entirely free of any phytotoxic symptoms. A score of 7 or 8 was regarded as representing a level of crop damage that was acceptable in order to obtain good control of weeds. Figure 2 shows the amount of weed growth in the 15 treatments, expressed as the percentage of available ground surface with weed cover.

A *pre-planting application* of oxadiazon (treatment 3) was only marginally crop-safe, as it resulted in mild chlorosis, scorching and stunting. Pre-planting oxadiazon controlled weeds initially, but by the end of June this control had failed.

Most post-planting treatments resulted in varying degrees of damage to the crop. *Pre-emergence treatments* initially caused crop damage in the form of chlorosis, scorching and stunting, though, with the exception of lenacil + linuron (treatment 4), the crop recovered from the initial damage to a variable extent (treatments 5-9), with applications of isoxaben + metazachlor and of the experimental material, 212H, achieving a just acceptable effect. With the exception of 212H, which was ineffective in weed control in this trial, the pre-emergence treatments offered reasonable weed control into July, with lenacil + linuron, chlorpropham + linuron and pendimethalin + metribuzin achieving the best effects.

The post-emergence herbicide applications all resulted in some degree of damage (again in the form of chlorosis, scorching and stunting) to plants that had been growing well before treatment. In the case of *early post-emergence applications*, lenacil + metamitron and isoxaben/terbuthylazine + bentazone, but not 212H, caused mild damage that was marginally acceptable (treatments 10-12). Of these three, isoxaben/terbuthylazine + bentazone alone resulted in excellent weed control.

The scorching and stunting caused by *later post-emergence applications* – of metamitron + asulam + mineral oil, bentazone and florasulam (treatments 13-15) – were more severe and, in any case, failed to control weeds adequately.

Marketable stems cropped from successful herbicide-treated plots were comparable in quality to stems from the hand-weeded plots.

The untreated plots rapidly became dominated by fat hen and pale persicaria, with only occasional other weeds competing. The weed species present in the trial overall, ranked in order of relative frequency all plots and assessment dates, are shown in Table 4. The other principal weeds present (in descending order) were small nettle, common chickweed, black nightshade, scentless mayweed, speedwell, groundsel and shepherd's purse.

From the viewpoint of crop safety, there appeared to be the possibility of a herbicide programme for alstroemeria based on a combination of pre-emergence isoxaben + metazachlor and early post-emergence isoxaben/terbuthylazine + bentazone. Unfortunately it became clear in the course of the trial that, contradicting earlier indications, the experimental material 212H was unlikely to become available to growers (C. Knott, personal communication).

This recommendation could be enhanced through a further trial to improve weed control without compromising crop safety, and a trial protocol (see Appendix) was made to the HDC BOF Panel in January 2007. This proposal was not approved.

Figure 1. Crop tolerance scores for alstroemeria following a range of herbicide treatments (see Table 1 for details). Values are based on assessments at four dates from 15 June to 28 July. Scores of 8+ (indicated by the dotted line) were considered acceptable.

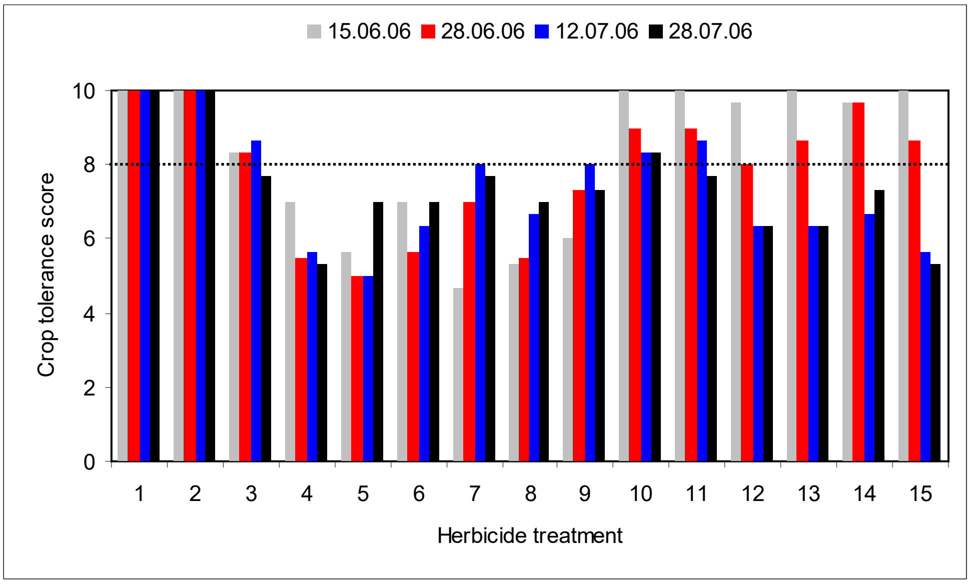

Figure 2. Weed cover of alstroemeria plots following a range of herbicide treatments (see Table 1 for details). Values based on assessments at four dates from 15 June to 28 July. The dotted line indicates 20% weed cover.

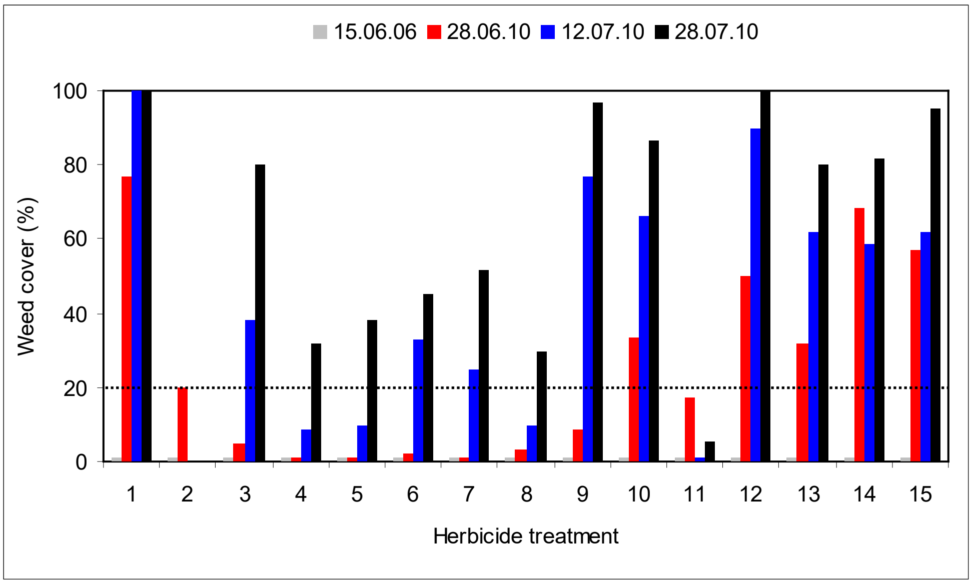

Table 4. Occurrence of weed species in the alstroemeria trial. The weeds have been ranked in order of their relative frequency (see text) in the plots, most common at the top. A '+' indicates that the species was present in the specified herbicide treatment when assessed about 2 weeks after application.

Weed species	*Relative frequency*	*Herbicide treatment (see Table 1 for details)*												
		3	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Small nettle *Urtica urens*	45	+	+			+	+	+	+		+	+	+	
Pale persicaria *Polygonum lapathifolium*	45		+	+		+	+	+	+		+			
Fat hen *Chenopodium album*	39								+		+		+	+
Common chickweed *Stellaria media*	33	+		+		+	+	+	+		+	+		
Black nightshade *Solanum nigrum*	32		+	+	+			+	+			+		
Scentless mayweed *Tripleurospermum maritimum*	30			+			+		+		+	+	+	
Speedwell *Veronica persica*	29	+	+	+				+	+		+	+	+	+
Groundsel *Senecio vulgaris*	26		+		+		+		+				+	
Shepherd's purse *Capsella bursa-pastoris*	19							+	+		+			
Spear thistle *Cirsium vulgare*	11		+	+			+			+			+	
Knotgrass *Polygonum aviculare*	8									+	+			
Annual poa *Poa annua*	5									+	+			
Sow-thistle *Sonchus oleraceus*	3		+								+			
Black bindweed *Fallopia convolvulus*	3				+									
Common fumitory *Fumaria officinalis*	1							+						
Red Shank *Polygonum persicaria*	1						+							

<u>Dahlia</u>

Crop tolerance to treatments is shown for representative assessment dates in Figure 3. The crop tolerance score used runs from 0, representing a lethal effect of the herbicide on the dahlia crop, to 10, meaning the crop was entirely free of any phytotoxic symptoms. A score of 7 or 8 was regarded as representing a level of crop damage that was acceptable in order to obtain good control of weeds. Figure 4 shows the amount of weed growth in the 12 treatments, expressed as the percentage of available ground surface with weed cover.

Most of the seven *pre-emergence treatments* were crop-safe. The crop tolerance scores never fell below 9 for the following treatments: oxadiazon, lenacil + linuron, chlorpropham + linuron and the experimental material 212H (treatments 3, 4, 5 and 9). The remaining treatments, metribuzin, isoxaben + metazachlor and pendimethalin + metribuzin (treatments 6 - 8), resulted in increasing but mild stunting over the growing season, though in none of the treatments did the crop tolerance scores reach 7. There was virtually no weed cover where the following treatments had been used: lenacil + linuron, chlorpropham + linuron and pendimethalin + metribuzin; where 212H had been used weed cover was <10%; for the remaining pre-emergence treatments percentage weed cover increased slowly, reaching about 20% in late August. An application of lenacil + linuron or chlorpropham + linuron gave the best combination of crop safety and weed control, with the experimental material 212H being a possible alternative.

Of the two *early post-emergence treatments* (treatments 10 and 11), 212H was entirely crop-safe and led to only about 10% weed cover, but lenacil + metamitron gave slight crop damage (highest crop tolerance score >8) but led to an about 50% weed cover by the end of the growing season.

Using an *early and late post-emergence programme* of metamitron, asulam + mineral oil (treatment 12) resulted in severe crop damage – chlorosis and scorching - by soon after the second application; with this treatment weed cover rose to about 20% by the end of the growing season.

Marketable stems cropped from successful herbicide-treated plots were comparable in quality to stems from the hand-weeded plots. In the case of dahlia treated with lenacil + linuron there was a slight delay in flowering.

The weed species present in the trial plots, ranked in order of frequency of occurrence across all plots and assessment dates, are shown in Table 5. Common chickweed was the commonest weed, followed (in descending order) by groundsel, shepherd's purse, small nettle, black nightshade, pale persicaria, sow-thistle, fat hen, speedwell, scentless mayweed and annual poa. The weed population, counted in untreated control plots on 25 July 2006, was dominated by shepherd's purse (89/m^2). Other species present were common chickweed and small nettle (each 9/m^2), black nightshade (6/m^2), scentless mayweed and speedwell (each 3/m^2), sow-thistle (2/m^2) and groundsel, annual poa, fat hen and pale persicaria (1/m^2 or less of each).

For dahlias, a pre-emergence application of lenacil + linuron or chlorpropham + linuron appeared to be the best option, though other products tested here could be alternatives if slight crop damage or weed growth were acceptable. There may be scope for post-emergence testing of metamitron, alone or in combination with lenacil. The experimental material 212H was useful in some cases but is apparently not now likely to become available to growers (C. Knott, personal communication).

This recommendation could be enhanced through a further trial, and a proposal (see Appendix) was made to the HDC BOF Panel in January 2007, although it was not approved. Since dahlias are also raised as pot-grown plants, and may stand out on the nursery for over a year, developing a weed problem, it was suggested that pot-, as well as field-raised dahlia, should be tested.

Figure 3. Crop tolerance scores for dahlia following a range of herbicide treatments (see Table 2 for details). Values based on assessments at five dates from 29 June to 25 August. Scores of 8+ (indicated by the dotted line) were considered acceptable.

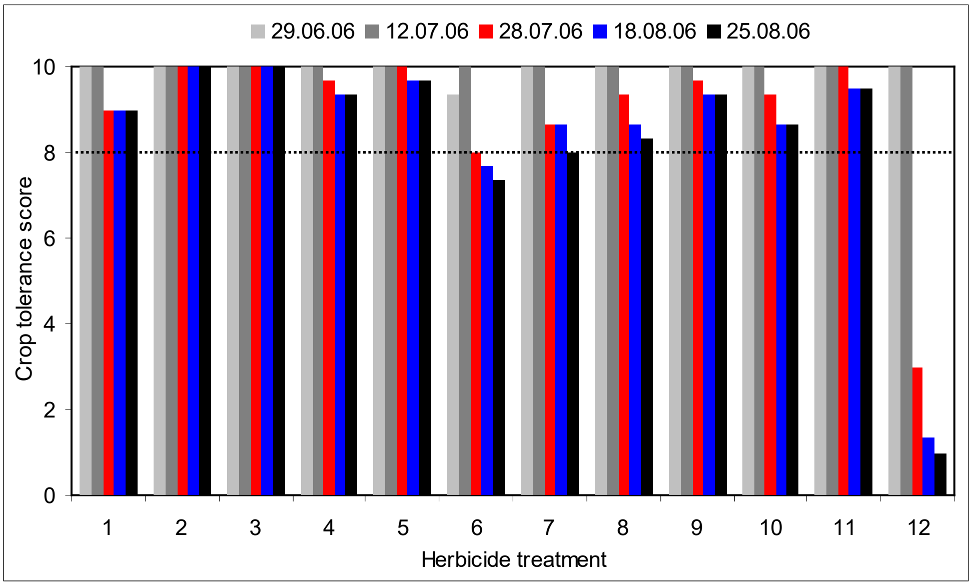

Figure 4. Weed cover of dahlia plots following a range of herbicide treatments (see Table 2 for details). Values based on assessments at five dates from 29 June to 25 August. Dotted line at 20% weed cover.

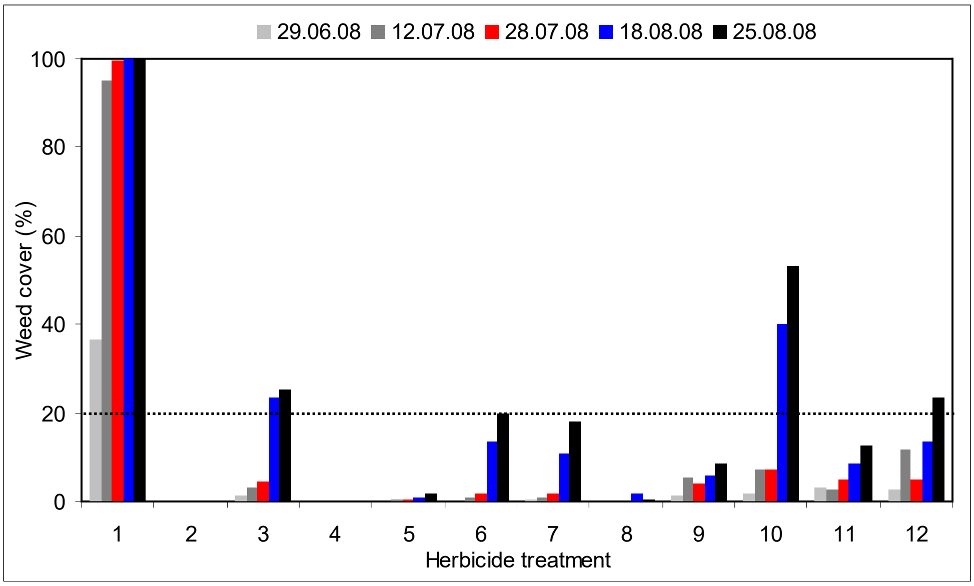

Table 5. Occurrence of weed species in the dahlia trial. The weeds have been ranked in order of their relative frequency (see text) in the plots, most common at the top. A '+' indicates that the species was present in the specified herbicide treatment when assessed about 2 weeks after application.

Weed species	*Relative frequency*	*Herbicide treatment (see Table 1 for details)*									
		3	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Common chickweed *Stellaria media*	40	+				+		+	+	+	
Groundsel *Senecio vulgaris*	31	+				+			+	+	
Shepherd's purse *Capsella bursa-pastoris*	29					+		+	+	+	+
Small nettle *Urtica urens*	28	+				+		+	+	+	
Black nightshade *Solanum nigrum*	24				+				+	+	
Pale persicaria *Polygonum lapathifolium*	18							+			
Sow-thistle *Sonchus oleraceus*	10					+				+	
Fat hen *Chenopodium album*	10							+	+		
Speedwell *Veronica persica*	9									+	
Scentless mayweed *Tripleurospermum maritimum*	6									+	
Annual poa *Poa annua*	3										
Spear thistle *Cirsium vulgare*	1										+
Red dead-nettle *Lamium purpureum*	1										
Knotgrass *Polygonum aviculare*	1										

Pot-grown agapanthus

In the trial with pot-grown agapanthus, and despite regular inspections throughout the June to September period, no symptoms of crop damage were seen for any of the products tested (Table 3). Marketable stems cropped from herbicide-treated pots were comparable in quality to stems from the hand-weeded pots. Despite ample opportunities for weed ingress before and after the pot-grown plants were received at Kirton (where the site in which they were grown had high weed populations), in this trial few weeds germinated and weed cover never exceeded two or three percent. Of the few weeds seen in the trial (Table 6), annual meadow grass and sorrel were most frequent, and, along with willow herb, probably originated before the pots were supplied to Kirton. Sorrel, but not grass, was controlled by herbicides used. A few examples of the typical weed species of the trial site germinated in the pots.

As well as growing in pots, agapanthus are grown in the field for flower and plant production, and further herbicide trials should be conducted under the more challenging conditions of weed pressure in the field. A proposal for such work (see Appendix) was made to the HDC BOF Panel in January 2007, although it was not approved.

Table 6. Occurrence of weed species in the pot-grown agapanthus trial. The weeds have been ranked in order of their relative frequency (see text) in the plots, most common at the top. A '+' indicates that the species was present in the specified herbicide treatment when assessed about 2 weeks after application.

Weed species	*Relative frequency*	*Herbicide treatment (see Table 1 for details)*							
		3	*4*	*6*	*7*	*8*	*9*	*10*	*11*
Annual poa *Poa annua*	16			+		+	+	+	+
Sorrel *Oxalis latifolia*	11								
Groundsel *Senecio vulgaris*	4			+				+	
Common fumitory *Fumaria officinalis*	4							+	+
Sow-thistle *Sonchus oleraceus*	2						+		
Willow herb *Chamaenerion angustifolium*	1								+
Spear thistle *Cirsium vulgare*	1								

Conclusions

1. Earlier HDC-funded projects have led to herbicide recommendations for sweet william (BOF 29), natural-season chrysanthemum (BOF 30), larkspur (BOF 40), china aster, cornflower, zinnia, larkspur, bupleurum, stock, snapdragon and delphinium (BOF 51). In the present project extension, some herbicides were tested on three further flower crops put forward by the HDC BOF Panel – alstroemeria, dahlia and pot-grown agapanthus.

2. From these trials there appeared to be a crop-safe herbicide programme for alstroemeria based on a combination of pre-emergence isoxaben + metazachlor and early post-emergence isoxaben/terbuthylazine + bentazone.

3. For dahlias, a pre-emergence application of lenacil + linuron or chlorpropham + linuron appeared to be the best option, though other products tested here could be alternatives if slight crop damage or weed growth were acceptable. There may be scope for post-emergence testing of metamitron, alone or in combination with lenacil. Since dahlias are also raised as pot-grown plants, and may stand out on the nursery for over a year developing a weed problem, likely herbicides should also be tested on pot-grown tubers.

4. The herbicides tested on established, pot-grown agapanthus were all crop-safe under the conditions used. They included oxadiazon, propachlor, isoxaben + metazachlor, lenacil + metamitron, isoxaben/terbutylazine + bentazone, metamitron followed by metamitron + asulam + mineral oil, bentazone and florasulam. As well as being growing in pots, agapanthus are also grown in the field for flower and plant production, and further herbicide trials need to be conducted under the more challenging conditions of weed pressure in the field.

5. The experimental material 212H proved useful in some cases, but unfortunately is not now likely to become available to growers.

6. The above findings could be enhanced through further trials (see Appendix).

Acknowledgements

We thank Christopher Hill, Rodney Asher and our other colleagues at Kirton for their skilful help in carrying out this project.

Appendix: Recommendations for further trialling

Table A1. Herbicide treatments for bed-grown Spanish tunnel *Alstroemeria*

	Herbicide treatment - shown as active ingredients, (formulations)and rates (formulations and rates shown only at first mention)			
	Pre-shoot-emergence	*Early-post-shoot-emergence*	*Shoots 5-20cm long*	*Late-season*
1 **untreated**	---	---	---	---
2 **hand-weeded**	---	---	---	---
3	**chlorpropham + linuron** (MSS 50CIPC + Alpha Linuron 50 SC, 440 g/L + 500g/L) at 6.0L + 1.0L/ha	---	---	**bentazone** (Basagran SG, 87% w/w) at 1.65 kg/ha **OR florasulam** (Boxer, 50 g/L) at 100 ml/ha AS NEEDED
4	**chlorpropham + linuron**	**isoxaben / terbuthylazine** + **bentazone** (Skirmish, 75/420 g/L + Basagran SL, 87%w/w) at 0.75L + 1.0L/ha	---	As above
5	**chlorpropham + linuron**	**metamitron** (Goltix WG, 70% w/w) at 2.5kg/L	**metamitron + asulam + mineral oil** (Goltix 400 g/L + Asulox 95% + CropSpray mineral oil) at 2.5kg + 2.0L + 3.0L/ha	As above
6	**isoxaben + metazachlor** (Flexidor 125 g/L + Butisan 500 g/L) at 2.0L + 2.5L/ha	---	---	As above
7	**isoxaben + metazachlor**	**isoxaben / terbuthylazine** + **bentazone**	---	As above
8	**isoxaben + metazachlor**	**metamitron**	**metamitron + asulam + mineral oil**	As above
9	**pendimethalin + metribuzin** (Stomp 400 g/L + Sencorex WG 70% w/w) at 3.3L + 0.5kg/ha	---	---	As above
10	**pendimethalin + metribuzin**	**isoxaben / terbuthylazine** + **bentazone**	---	As above
11	**pendimethalin + metribuzin**	**metamitron**	**metamitron + asulam + mineral oil**	As above

Table A2. Herbicide treatments for field-grown and pot-grown *Dahlia*

	Herbicide treatment - shown as active ingredients, (formulations)and rates (formulations and rates shown only at first mention)		
	Pre-shoot-emergence	*Early-post-shoot-emergence*	*Late-season*
1 **untreated**	---	---	---
2 **hand-weeded**	---	---	---
3	**oxadiazon** (Ronstar) at 4.0L/ha	---	---
4	**oxadiazon**	**lenacil + metamitron** (Venzar 440 g/L + Goltix WG 70% w/w) at 4.0L + 0.75L	---
5	**oxadiazon**	**metamitron** (Goltix WG, 70% w/w) at 2.5kg/ha	**metamitron** AS NEEDED
6	**lenacil + linuron** (Venzar Flowable + Alpha Linuron 50 SC, 440g/L + 500g/L) at 2.0L +1.7L/ha	---	---
7	**lenacil + linuron**	**lenacil + metamitron**	---
8	**lenacil + linuron**	**metamitron**	**metamitron** AS NEEDED
9	**chlorpropham + linuron** (MSS 50CIPC + Alpha Linuron 50 SC, 440 g/L + 500g/L) at 6.0L + 1.0L/ha	---	---
10	**chlorpropham + linuron**	**lenacil + metamitron**	---
11	**chlorpropham + linuron**	**metamitron**	**metamitron** AS NEEDED

Table A3. Herbicide treatments for field-grown *Agapanthus*

	Herbicide treatment - shown as active ingredients, (formulations)and rates (formulations and rates shown only at first mention)			
	Post-planting, pre-weed-emergence	*Early-post-weed-emergence*	*Late-post-weed-emergence*	*Late-season*
1 **untreated**	---	---	---	---
2 **hand-weeded**	---	---	---	---
3	**oxadiazon** (Ronstar 20 granular) at 200kg/ha	---	---	**bentazone** (Basagran SG, 87% w/w) at 1.65 kg/ha **OR florasulam** (Boxer, 50 g/L) at 100 ml/ha AS NEEDED
4	**oxadiazon**	**lenacil + metamitron** (Venzar 440 g/L + Goltix WG 70% w/w) at 4.0L + 0.75L	---	As above
5	**oxadiazon**	**isoxaben / terbuthylazine** (Skirmish, 75/420 g/L) + **bentazone** (Basagran SL, 87%w/w) at 0.75L + 1.0L/ha	---	As above
6	**oxadiazon**	**metamitron** (Goltix WG, 70% w/w) at 2.5kg/ha	**metamitron + asulam + mineral oil** (Goltix 400 g/L + Asulox 95% + CropSpray mineral oil) at 2.5kg + 2.0L + 3.0L/ha	As above
7	**isoxaben + metazachlor** (Flexidor 125 + Butisan, 125 g/L + 500 g/L) at 2.0L + 2.5L	---	---	As above
8	**isoxaben + metazachlor**	**lenacil + metamitron**	---	As above
9	**isoxaben + metazachlor**	**isoxaben / terbuthylazine** + **bentazone**	---	As above
10	**isoxaben + metazachlor**	**metamitron**	**metamitron + asulam + mineral oil**	As above