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PRE- AND POST-EMERGENCE ACTIVITY, SELECTIVITY AND PERSISTENCE OF THE HERBICIDE TRALKOXYDIM (FD 4026)

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1. SUMMARY

Pot experiments were used to investigate the phytotoxicity of the herbicide tralkoxydim (FD 4026). In the initial experiment, tralkoxydim at 50, 150 and 450 g a.i. ha^{-1} was applied using four different methods to determine its type of activity and routes of herbicide entry into the plants of six target species. In separate experiments, tralkoxydim at 40, 160 and 640 g a.i. ha^{-1} was tested for pre- and post-emergence activity and selectivity on up to 18 temperate crop species and 28 temperate weed species. The surfactant 'Agral' was added at 0.1% v/v to all tralkoxydim treatments in all experiments. The selectivity experiments also included a second series of cereal crops that were seed-dressed with the safener, 1,8-napthalic anhydride (NA), in order to investigate possible protection from herbicide injury. Persistence of active soil residues of tralkoxydim was also assessed.

In the first experiment, both pre- and post-emergence treatments of tralkoxydim were found to be active against the monocotyledonous species tested. Post-emergence treatments were active when applied to the foliage only or to the soil only. Dicotyledonous species were unaffected by all tralkoxydim treatments.

In the pre-emergence selectivity experiment, tralkoxydim was tolerated by cereals, onion, brassica crops, sugar beet and other dicotyledonous crops tested at doses to which some important grass weeds, including Alopecurus myosuroides, were susceptible. Perennial ryegrass proved to be very sensitive to tralkoxydim. The tolerance of barley and oat to tralkoxydim was increased with a seed-dressing of NA safener. In the post-emergence selectivity experiment, excellent tolerance to tralkoxydim was shown by wheat, barley, oilseed rape, sugar beet, legume crops and other dicotyledonous crops tested at doses which killed the intractable grass weeds, Alopecurus myosuroides and Avena fatua. Perennial ryegrass, oat and maize were sensitive to tralkoxydim, while the important grass weeds Bromus sterilis and Elymus repens showed appreciable tolerance. The tolerance of oat and maize was improved by a seed-dressing of NA safener.

Soil-persistence of phytotoxic tralkoxydim residues to perennial ryegrass was short compared with the herbicides cyanazine (short persistence) and simazine (long persistence).

2. INTRODUCTION

In the past, pre- and post-emergence activity and selectivity of new herbicides have been investigated by LARS Crop and Environmental Sciences Department on a range of temperate crop and weed species, grown in pots. Such information can indicate possible alternative uses to those specified by the originating company, e.g. weed control in minor crops, and give pointers to potential problems, e.g. adverse effects on non-target species. Persistence in the soil has also been assessed, providing data which, in conjunction with data on crop susceptibilities, are useful in considering subsequent cropping of treated land. Although in these investigations, seeds or plants from only one crop variety or source of weed species have been sown in one soil-type at one depth, the results provide guidelines for more detailed studies where warranted.

Tralkoxydim is a herbicidal active ingredient discovered by Imperial Chemical Industries (ICI) Australia and developed jointly with ICI Plant Protection Division. The original information received from ICI (now ZENECA Agrochemicals) suggested that tralkoxydim had potential for selective post-emergence control of some important grass weeds in the UK, particularly Avena fatua, Alopecurus myosuroides and Lolium spp., in wheat and barley. Tralkoxydim was approved for use in the UK as 'Grasp' during 1993.

Warner et al. (1987), investigating the mode of action of tralkoxydim, reported that, in glasshouse studies, tralkoxydim activity was mostly through the foliage and there was rapid uptake and translocation from treated foliage to the growing points, inferring a high degree of rainfastness. Under field conditions, treatments applied to grass weeds with 2-3 leaves (mid-February) gave a slow but effective kill, while later treatments, applied at early tillering (early March), were quicker-acting (Sutton et al. 1987). Results from field trials in Germany, France and the UK (Sutton et al. 1987) showed that tralkoxydim was effective against Avena spp., Lolium spp. and Alopecurus myosuroides at doses of 200-350 g a.i. ha^{-1}. One of the advantages of using tralkoxydim is that good control is achieved for Avena and Lolium spp. over a wide range of growth stages, (from the 2-3 leaf stage to stem elongation for Avena fatua). However, treatment of Alopecurus myosuroides at early growth-stages was found to be critical for effective control (Sutton et al. 1987). Other plus points for tralkoxydim are its low toxicity to mammals, birds and fish, and its rapid degradation in soil; the half-life in soil under aerobic conditions is less than four days (Warner et al. 1987).

This present report describes the pre- and post-emergence activity, and selectivity, of tralkoxydim in temperate species and its potential for soil-persistence. Results from an experiment which investigated the response of plants to tralkoxydim applied separately to the shoot, root or seed, are also included to provide information on the route of herbicide entry into the plant, and on the type and degree of phytotoxicity.

3. MATERIALS AND METHODS

3.1 Herbicide details

Source: ICI Plant Protection Division,
(now Zeneca Agrochemicals)
Fernhurst, Haslemere,
Surrey GU27 3JE

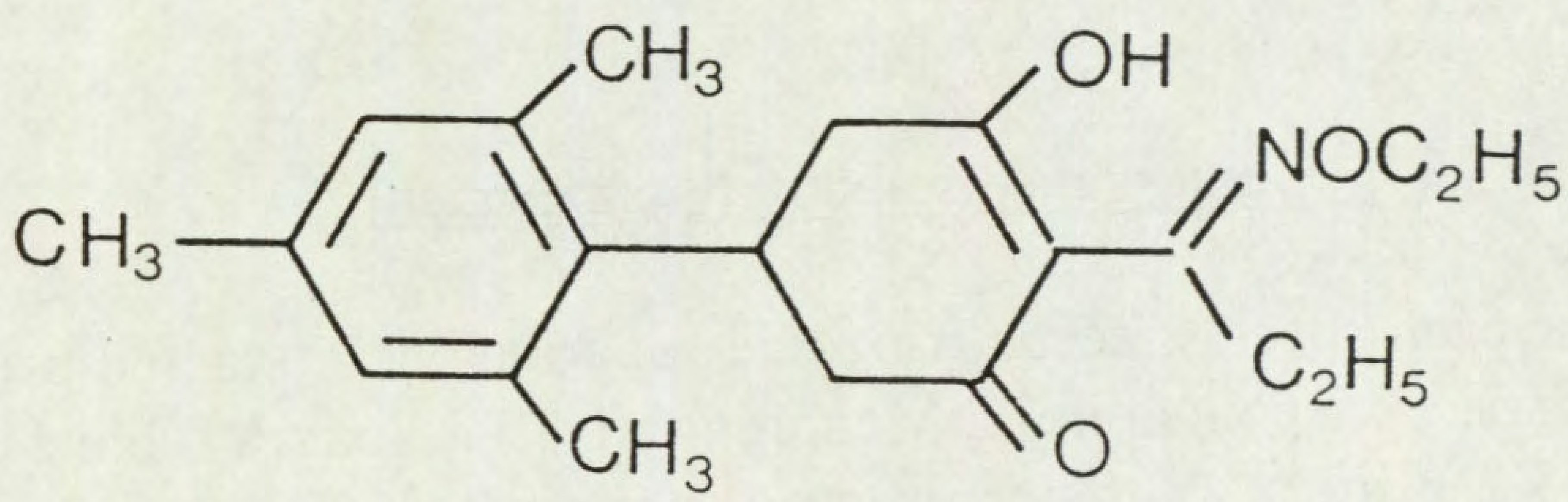
Code number: FD 4026 (PP 604)

Common name: Tralkoxydim

Trade name: GRASP

Chemical name: (IUPAC) 2-[1-(ethoxyimino)propyl]-3-hydroxy-5-(2,4,6-trimethylphenyl)cyclohex-2-enone

Chemical structure:



Formulation used: 100 g $litre^{-1}$ emulsifiable concentrate

Doses applied: Activity experiment:-
50, 150 and 450 g a.i. ha^{-1}

Selectivity experiments:-
40, 160 and 640 g a.i. ha^{-1}

The surfactant polyoxyethylene nonylphenol (Agral, 900g a.i. $litre^{-1}$, Zeneca) was added at 0.1% v/v to all tralkoxydim treatments in all experiments.

3.2 Activity experiment

This was carried out in a glasshouse on six species, using the techniques described by Richardson and Dean (1974). Species information and the growth stages of plants at spraying and assessment are summarised in Appendix 1. The four annual species were raised from seeds, the two perennials from rhizome fragments, in 9 cm diameter pots containing a Mendip sandy clay loam (Table 1). Environmental conditions and dates of spraying and assessments are given in Table 2. Herbicides were applied by four different methods.

(i) A post-emergence spray to the foliage only, avoiding contact with the soil

(ii) A post-emergence soil drench, avoiding contact with the foliage

(iii) Pre-emergence to the soil surface

(iv) Pre-emergence with incorporation to a depth of 5 cm before planting

There were two replicates for each treatment. After spraying, pots were set out in two randomised blocks per species in a heated glasshouse (Table 2) where normal daylight was supplemented by mercury vapour lamps to provide 14 h photoperiods. Irrigation was by hand-watering and for methods (i) and (ii) this was onto the soil only, avoiding the foliage.

3.3 Pre-emergence selectivity experiment

For each species, seeds, rhizomes or roots were planted prior to spraying in 9 cm diameter plastic pots containing a Mendip sandy clay loam (Table 1) with Vitax Q4 fertiliser added at 3.3 g litre^{-1}. Numbers of seeds per pot, depths of sowing, seed sources and growth stages at assessment are described in Appendix 2.

To improve germination, Chenopodium album seeds were kept in a 0.1M potassium nitrate solution for 48 h in the light before sowing and Fallopia convolvulus seeds were stored at 4°C in moist sand for two weeks before sowing. Cirsium arvense root fragments were soaked in thiram (0.55 g litre^{-1}) for one hour to protect them from soil-borne pathogens. The brassica crops and cruciferous weeds were given a soil drench with Cheshunt compound, (ammonium carbamate + copper sulphate) at 3.05 g litre^{-1}, one week after spraying to prevent damping-off disease. An additional series of wheat, barley, oat and maize seeds were treated with the safener, 1,8-naphthalic anhydride (NA) formulated as a wettable powder, to investigate possible protection from herbicide injury. Seeds were dressed by shaking in a polyethylene bag with NA, at 0.5% of the seed weight.
The herbicide was applied as a pre-emergence surface spray using a laboratory track

sprayer. This was fitted with an 80015E Lurmark flat-fan Evenspray nozzle delivering 400 litres ha^{-1} at a pressure of 210 kPa (30 psi) and moving at 0.5 m sec^{-1}, 30 cm above the stationary pots. There were two replicates for each treatment. After spraying, pots were set out in three randomised blocks per species in a heated glasshouse (Table 2) where normal daylight was supplemented by mercury vapour lamps to provide 14 h photoperiods. Irrigation was by overhead hand-watering.

3.4 Post-emergence selectivity experiment

Plants were grown outside in 9 cm plastic pots containing Mendip loam plus fertiliser (as described in 3.2). Sowing dates were staggered so that the majority of species would reach a pre-determined growth stage (2-4 leaves) by the time of spraying. Before spraying, each species was thinned to the same number per pot. Plant numbers and growth are recorded in Appendix 3.

The herbicide was applied using a laboratory track sprayer fitted with an 80015E Lurmark flat fan nozzle delivering 328 litres ha^{-1} at a pressure of 210 kPa (30 psi) and moving at 0.5 m sec^{-1}, 45 cm above the target area of the plants. After spraying, plants were protected from rainfall for 24 h and then put outside in two randomised blocks per species. Watering was by natural rainfall plus additional overhead hand-watering as necessary. One week after spraying, pots were moved into a well ventilated glasshouse with automatic bright light shading to prevent extreme temperatures. This allowed individual watering of pots to maintain a uniform soil moisture level between pots having differing irrigation requirements due to the different herbicide effects on the plants and, thus, reduced unwanted effects from waterlogging or drought. Outside and glasshouse temperatures for the duration of the experiment are summarised in Table 2.

3.5 Assessments

Assessments were made five to six weeks after spraying pre-emergence, and three to four weeks after spraying post-emergence. Survivors were counted and scored for vigour on a 0-7 scale as follows:

- 0 = completely dead
- 1 = moribund, but not all tissue dead
- 2 = alive, with some green tissue, but unlikely to make much further growth
- 3 = very, stunted, but apparently still making some growth
- 4 = considerable inhibition of growth
- 5 = readily distinguishable inhibition of growth
- 6 = some detectable adverse effect as compared with untreated - colour difference, morphological abnormality, epinasty or slight reduction in growth
- 7 = indistinguishable from untreated control

Histograms of data are presented (Figures 1-7) for each treatment on each species, showing both plant survival and plant vigour, calculated as percentages of untreated controls. For the selectivity experiments, observed selectivities determined using the criteria specified, are presented in Tables 3 and 4, along with comments highlighting important results.

3.6 Persistence in soil

Residual phytotoxicity was assessed by bioassay on seven dates after spraying. Tralkoxydim at 40, 160 and 640 g a.i.ha^{-1} was applied as a surface spray to pots (7.5 cm diameter) containing Mendip loam plus fertilizer (as in 3.3). "Standard" treatments of cyanazine (short persistence) at 1000 g a.i.ha^{-1}, and simazine (long persistence) at 1000 g a.i.ha^{-1} were included. Pots were kept in a temperate glasshouse where night-time temperatures were not allowed to fall below 10°C and ventilation occurred during daytime above 15°C. Pots were watered from overhead as necessary to keep the soil moist.

For each bioassay, three replicate pots for each treatment were sown with perennial ryegrass (cv. Melle), 12 seeds pot^{-1} and 0.5 cm deep. Plants were harvested at a pre-determined growth stage of the untreated controls, the number and fresh weight of shoots being recorded. Bioassays commenced within a day of spraying and were repeated at seven to ten week intervals for one year. Residual phytotoxicity was considered to be negligible when plant numbers and shoot fresh weights exceeded 85% of the untreated control plants.

Results are presented graphically in Figure 8 (shoot weights only) and comments are made in the text.

3.6 Soil analysis and environmental conditions

Table 1. Soil analysis - Mendip sandy clay loam

Particle size analysis (%)		
Coarse sand	(600 μm - 2 mm)	2.1
Medium sand	(212 μm - 600 μm)	41.4
Fine sand	(63 μm - 212 μm)	13.8
Silt	(2 μm - 63 μm)	26.6
Clay	(<2 μm)	16.1
Organic matter (%)		4.6
pH (in water, 1 : 2, soil : water ratio)		6.0

Table 2. Environmental conditions

Experiment	Activity	Pre-emergence selectivity	Post-emergence selectivity	
Dates of spraying	15 Nov 1988	19 Jan 1989	28 Jul 1989 & 7 Aug 1989	
Main assessment completed	5 Jan 1989	14 Mar 1989	1 Sep 1989	
Temperature (°C)	Glasshouse	Glasshouse	Outside	Glasshouse
Mean	15	14	17	21
Maximum	21	22	28	32
Minimum	10	8	6	11
Relative humidity (%)				
Mean	62	67	-	77
Maximum	88	90	-	98
Minimum	35	40	-	50

4. RESULTS

4.1 Symptoms of tralkoxydim damage to plants

The most obvious symptoms from post-emergence treatments of tralkoxydim at lethal doses on sensitive grass species, such as Avena fatua, were a rapid inhibition of new growth, older sprayed leaves sometimes darkening or turning red, followed by leaf necrosis and death. At sub-lethal doses, new growth was stunted and chlorotic, and any tillers produced were also small with narrow yellowed leaves.

Pre-emergence treatments, at lethal doses, had no effect on germination but growth of sensitive grasses was often stopped between the coleoptile emerging through the soil surface and the first leaf appearing. When growth had stopped the shoots quickly turned necrotic and died. At sub-lethal doses, plants remained stunted and pale and in some grass species, particularly Avena fatua, there was suppression of secondary roots, giving poor anchorage to the soil and eventually causing the plants to collapse from the shoot base.

4.2 Activity experiment (Figure 1)

The three broad-leaved species, dwarf bean, kale and Polygonum amphibium were unaffected by all pre- and post-emergence treatments of tralkoxydim.

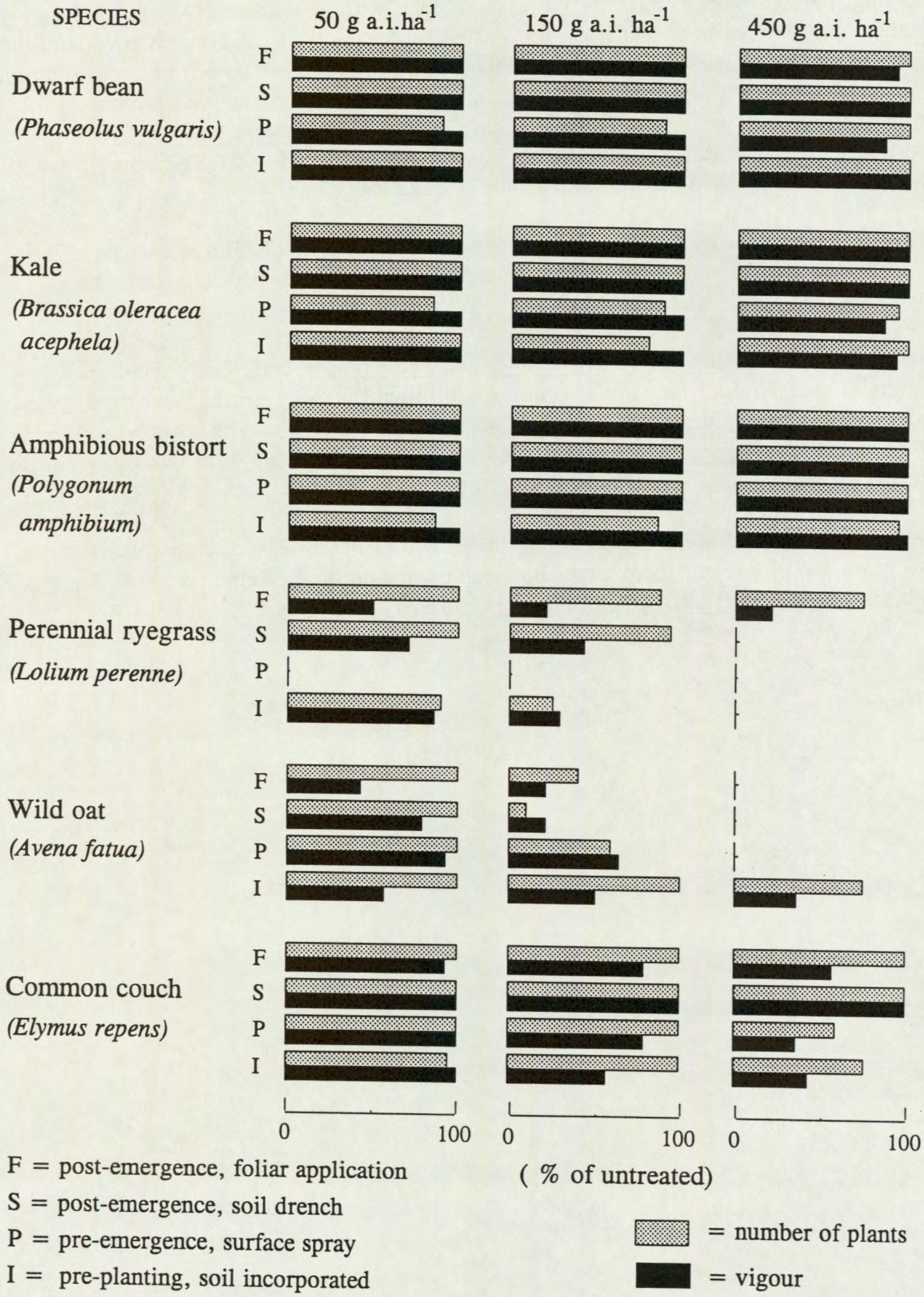
Perennial ryegrass was particularly sensitive to pre-emergence surface sprays of tralkoxydim at 50 g a.i. ha^{-1}, all plants being killed soon after emergence. The comparable pre-emergence soil incorporated treatment of tralkoxydim at 50 g a.i. ha^{-1} caused only slight growth suppression but the 150 g a.i. ha^{-1} dose caused severe damage or kill of perennial ryegrass. Pre-emergence treatments of tralkoxydim at 150 g a.i. ha^{-1}, as soil surface sprays or when incorporated into the soil, caused substantial suppression of Avena fatua growth. The 450 g a.i. ha^{-1} dose as a soil surface spray killed plants soon after emergence but plants were recovering after initial stunting from the soil incorporated treatment. Both pre-emergence application methods gave similar activity against Elymus repens, growth was moderately reduced by 150 g a.i. ha^{-1}, while 450 g a.i. ha^{-1} gave considerable initial supression of shoot and root systems but some plants were recovering.

Post-emergence treatments, applied to the foliage only or to the soil only, were active against perennial ryegrass and Avena fatua. At 50 g a.i. ha^{-1} the foliage-only treatment was the more active but responses were similar for both application methods at 150 and 450 g a.i. ha^{-1}, which prevented any growth after treatment. Elymus repens growth was moderately suppresssed by post-emergence foliage-only sprays of tralkoxydim at 450 g a.i. ha^{-1} but unaffected by soil drench treatments at the same dose.

Figure 1

ACTIVITY EXPERIMENT

Tralkoxydim (FD 4026)



4.3 Pre-emergence selectivity (Table 3 and Figures 2-4)

Wheat, with or without the NA safener applied as a seed dressing, was unaffected by tralkoxydim at 640 g a.i. ha^{-1}. Growth of barley, without safener, was slightly suppressed at 640 g a.i. ha^{-1} and unaffected at 160 g a.i. ha^{-1}, whereas with the NA safener seed dressing, barley was tolerant at 640 g a.i. ha^{-1}. Oat, with or without NA safener, was tolerant to tralkoxydim at 160 g a.i. ha^{-1}. At 640 g a.i. ha^{-1}, oat plants grown without the seed dressing of safener were severely damaged, while growth of oats from seeds with the safener was only slightly suppressed. Maize, with or without safener was tolerant at 160 g a.i. ha^{-1} but damaged at 640 g a.i. ha^{-1}. Perennial ryegrass proved very sensitive to pre-emergence treatments of tralkoxydim at 40 g a.i. ha^{-1} (the lowest dose tested); many plants emerged but died before reaching the one-leaf stage.

Most of the broad-leaved crops tested were unaffected by tralkoxydim at 640 g a.i. ha^{-1}, apart from dwarf bean and white clover, whose growth was slightly suppressed by 640 g a.i. ha^{-1} but unaffected by 160 g a.i. ha^{-1}.

The weed grasses, Alopecurus myosuroides and Poa trivialis, were badly damaged by tralkoxydim at 40 g a.i. ha^{-1} but effectively controlled by 160 g a.i. ha^{-1}, whereas Avena fatua and Poa annua were only controlled adequately by 640 g a.i. ha^{-1}. Growth of Festuca rubra and Elymus repens was reduced at 640 g a.i. ha^{-1} but plants were recovering, while growth of Bromus sterilis was only slightly affected at this dose.

Generally, tralkoxydim had no effect on the growth of broad-leaved weed species at 640 g a.i. ha^{-1}; however, there were appreciable reductions of emergence of Chrysanthemum segetum, Lamium purpureum and Viola arvensis.

Table 3 Crop tolerance and weed sensitivity to pre-emergence treatments of Tralkoxydim (FD 4026)

Dose (g a.i.ha^{-1})	Tolerant crops (plant number or vigour reduced by less than 15%)	Sensitive weeds (plant number or vigour reduced by 70% or more)
640	Wheat ± safener Barley + safener Onion Field bean Pea Sugar beet Oilseed rape Kale Swede Carrot Lettuce Sunflower	Avena fatua Poa annua (plus species listed below)
160	(Species listed above) Barley Oat ± safener Maize ± safener Dwarf bean White clover	Alopecurus myosuroides Poa trivialis (plus species listed below)
40	(Species listed above)	No weeds sensitive

Sensitive crops (severe damage or kill at 40 g a.i.ha^{-1})	Tolerant weeds (no or only slight to moderate effects at 640 g a.i.ha^{-1})
Perennial ryegrass	Bromus sterilis Broad-leaved weeds

Figure 2

PRE-EMERGENCE SELECTIVITY EXPERIMENT

Tralkoxydim (FD 4026)

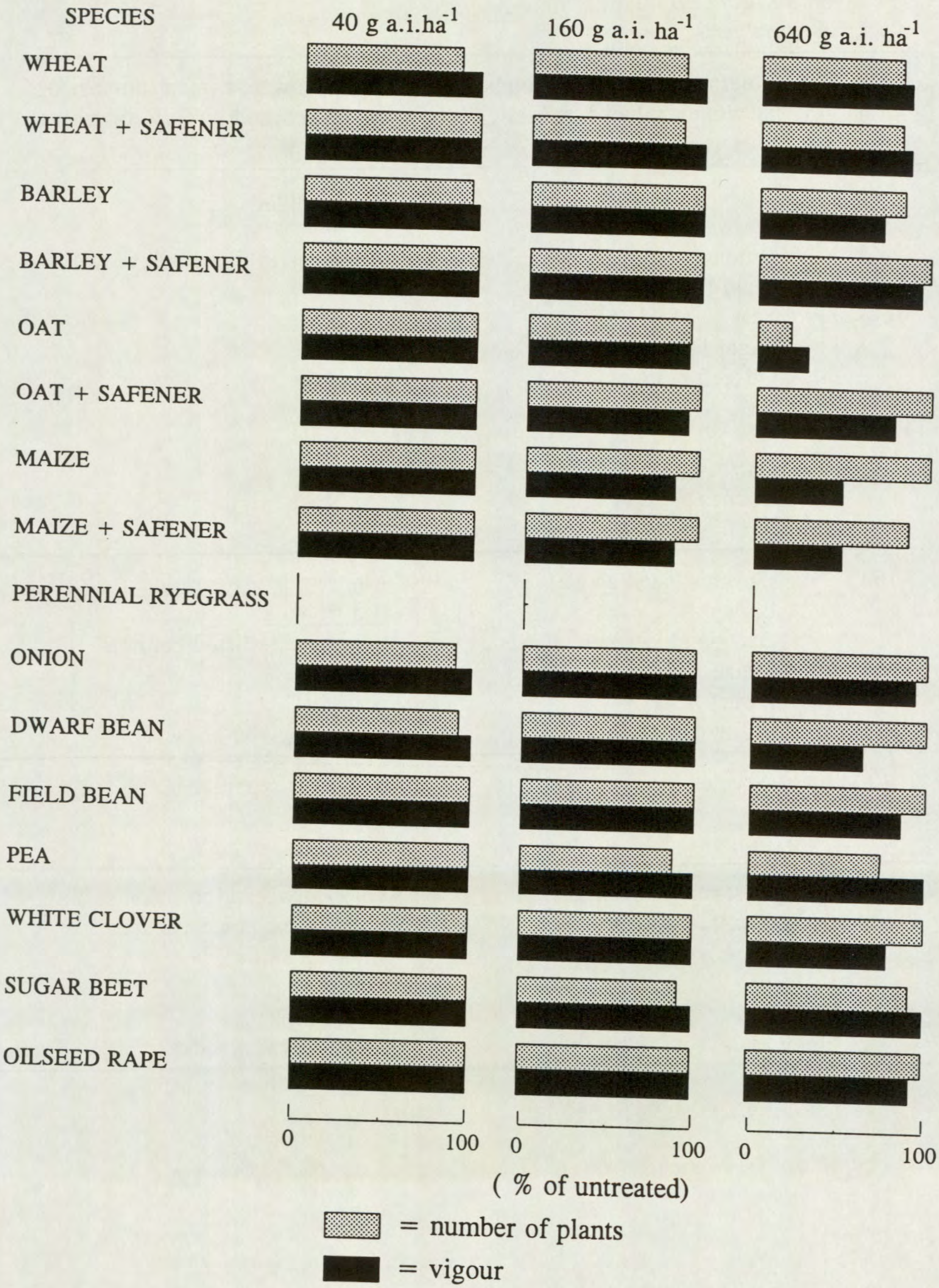


Figure 3 PRE-EMERGENCE SELECTIVITY EXPERIMENT

Tralkoxydim (FD 4026)

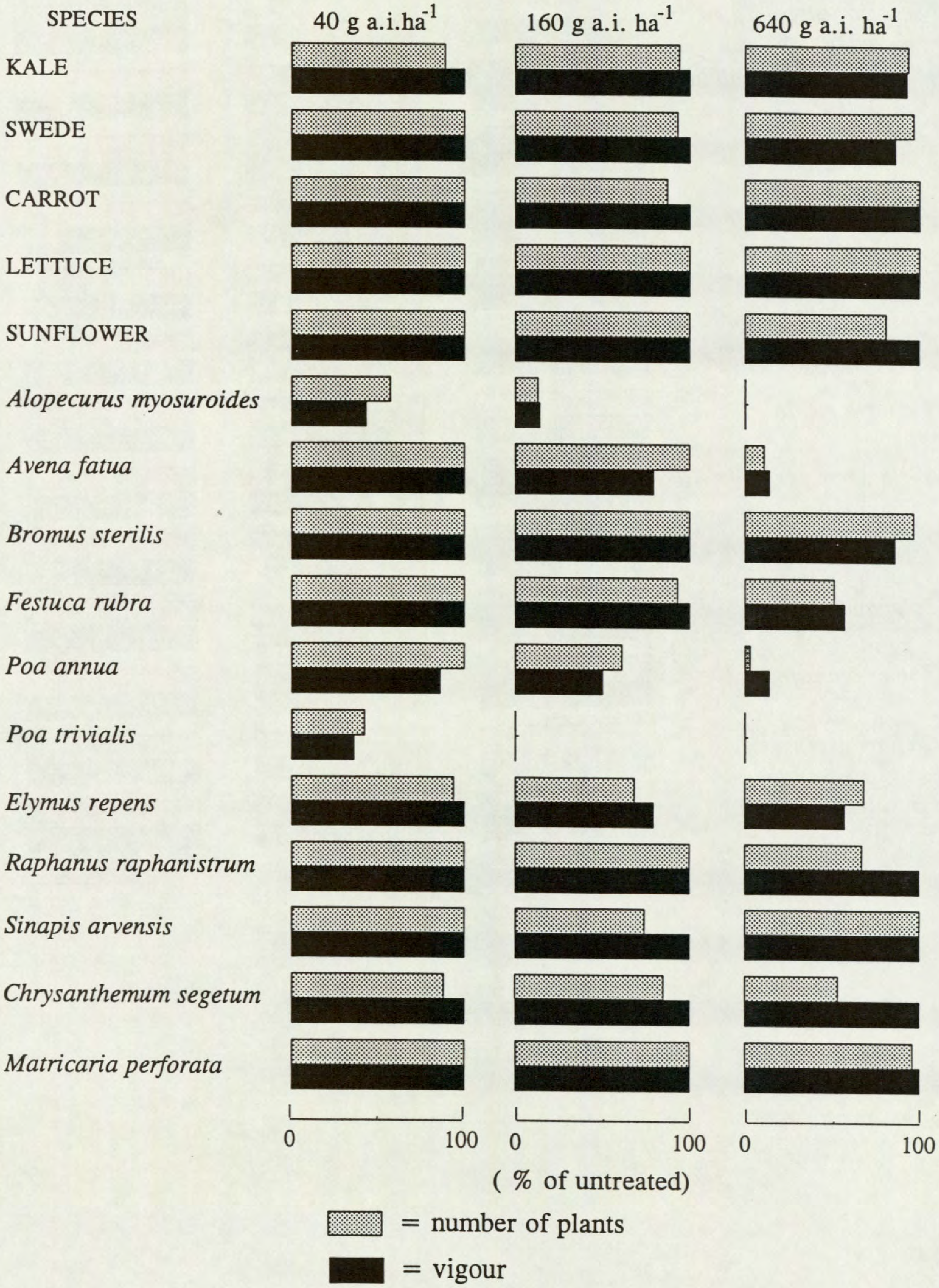
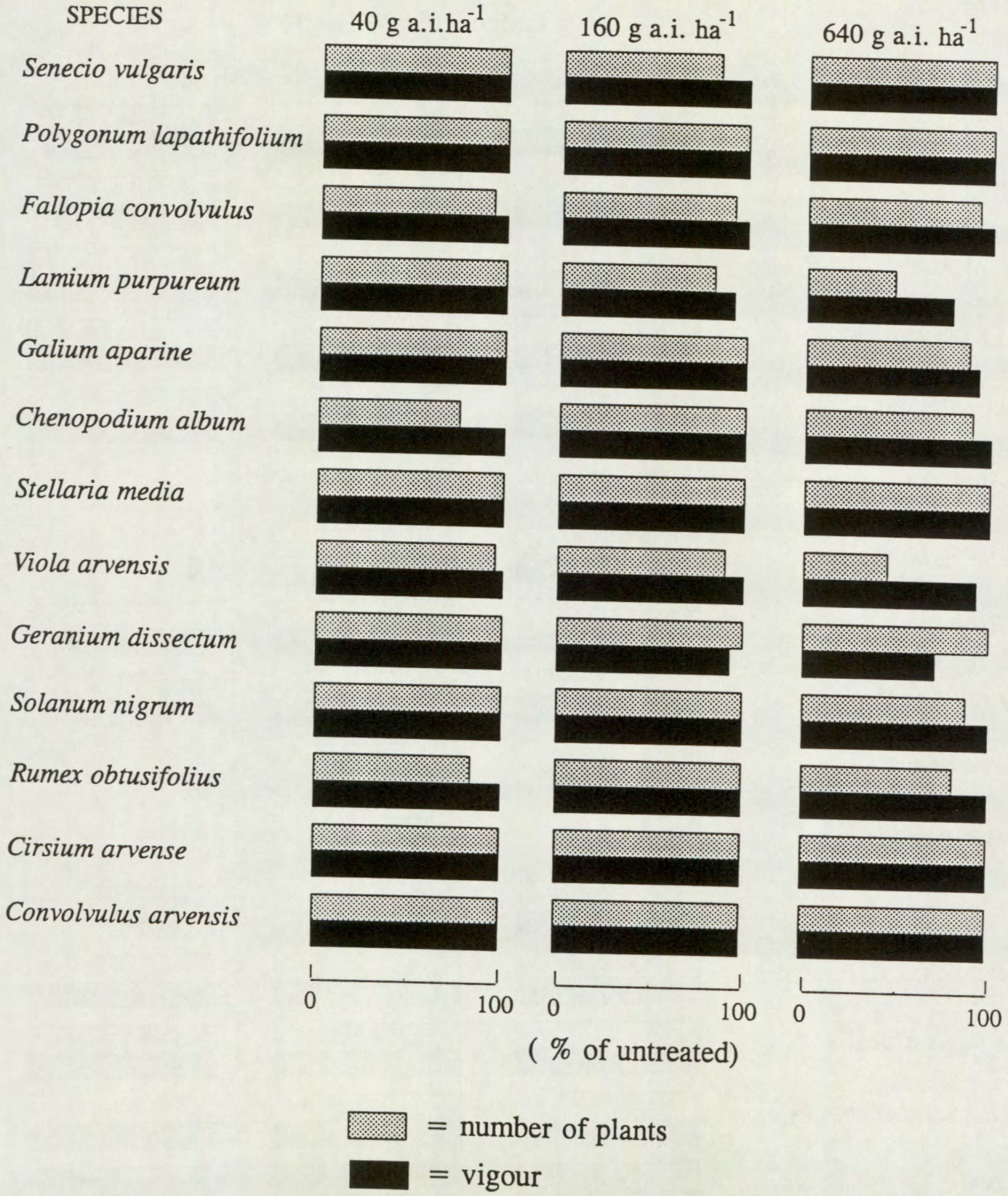


Figure 4 PRE-EMERGENCE SELECTIVITY EXPERIMENT

Tralkoxydim (FD 4026)



4.4 Post-emergence selectivity (Table 4 and Figures 5-7)

Wheat and barley, with or without seed dressings of the NA safener, showed excellent tolerance to tralkoxydim applied post-emergence at 640 g a.i. ha^{-1}. Oat plants without NA safener were killed by tralkoxydim at 40 g a.i. ha^{-1}, whereas growth of plants with the seed dressing of NA safener was only moderately suppressed. All oat plants were killed by 160 g a.i. ha^{-1} of tralkoxydim. Maize without the safener seed dressing was severely damaged or killed by 40 g a.i. ha^{-1}, whereas plants with the safener seed dressing survived 40 and 160 g a.i. ha^{-1}, although growth was stunted, but were killed by 640 g a.i. ha^{-1}. Perennial ryegrass proved very sensitive to tralkoxydim; plants were killed by 40 g a.i. ha^{-1}.

Onion and most of the broad-leaved crops tested were tolerant to tralkoxydim at 640 g a.i. ha^{-1}, except for kale and cabbage, which had growth moderately suppressed by 640 g a.i. ha^{-1}; plants were tolerant to 160 g a.i. ha^{-1}.

Alopecurus myosuroides, Avena fatua and Agrostis stolonifera plants were severely stunted or killed by tralkoxydim at 40 g a.i. ha^{-1} and all were killed by 160 g a.i. ha^{-1}. The number of Poa trivialis and Poa annua plants surviving was considerably reduced by 160 g a.i. ha^{-1} of tralkoxydim but, while P. trivialis survivors were stunted, those of P. annua were recovering vigorously. Both Poa spp. were killed by 640 g a.i. ha^{-1}. Bromus sterilis was unaffected at 160 g a.i. ha^{-1} but plant numbers and vigour were reduced by 640 g a.i. ha^{-1}. Elymus repens growth was only slightly reduced by 640 g a.i. ha^{-1}.

Tralkoxydim, applied post-emergence, had no effect on any of the broad-leaved weeds tested.

4.5 Soil persistence (Figure 8)

When perennial ryegrass seed was sown into soil, 24 h after spraying tralkoxydim onto the soil surface, the resultant plants were severely damaged by the 40 g a.i. ha^{-1} treatment and died soon after emergence from the 160 and 640 g a.i. ha^{-1} treatments. Plants from seed sown into the tralkoxydim-treated soil eight weeks after spraying were unaffected by any of the treatments.

Soil sprayed with cyanazine or simazine at 1000 g a.i. ha^{-1} proved to be lethal to perennial ryegrass plants from seed sown 24 h after spraying. There was only slight growth reduction of plants from seed sown into cyanazine-treated soil eight weeks after treatment, and no effects on plants from seed sown 16 weeks after soil-treatment. Simazine caused damage to perennial ryegrass plants from seed sown into treated soil up to 34 weeks after spraying, but no effects were apparent on plants at the 43 week bioassay.

Table 4 Crop tolerance and weed sensitivity to post-emergence treatments of tralkoxydim (FD 4026)

Dose (g a.i.ha^{-1})	Tolerant crops (plant number or vigour reduced by less than 15%)	Sensitive weeds (plant number or vigour reduced by 70% or more)
640	Wheat Wheat + safener Barley Barley + safener Onion Dwarf bean Field bean Pea White clover Sugar beet Oilseed rape Carrot Parsnip Lettuce Sunflower	Poa annua Poa trivialis (plus species listed below)
160	(Species listed above plus) Kale Cabbage	Avena fatua (plus species listed below)
40	(Species listed above)	Alopecurus myosuroides Agrostis stolonifera

Sensitive crops (severe damage or kill at 40 g a.i.ha^{-1})	Tolerant weeds (no or only slight to moderate effects at 640 g a.i.ha^{-1})
Perennial ryegrass Maize	Elymus repens Broad-leaved weeds

Figure 5 POST-EMERGENCE SELECTIVITY EXPERIMENT

Tralkoxydim (FD 4026)

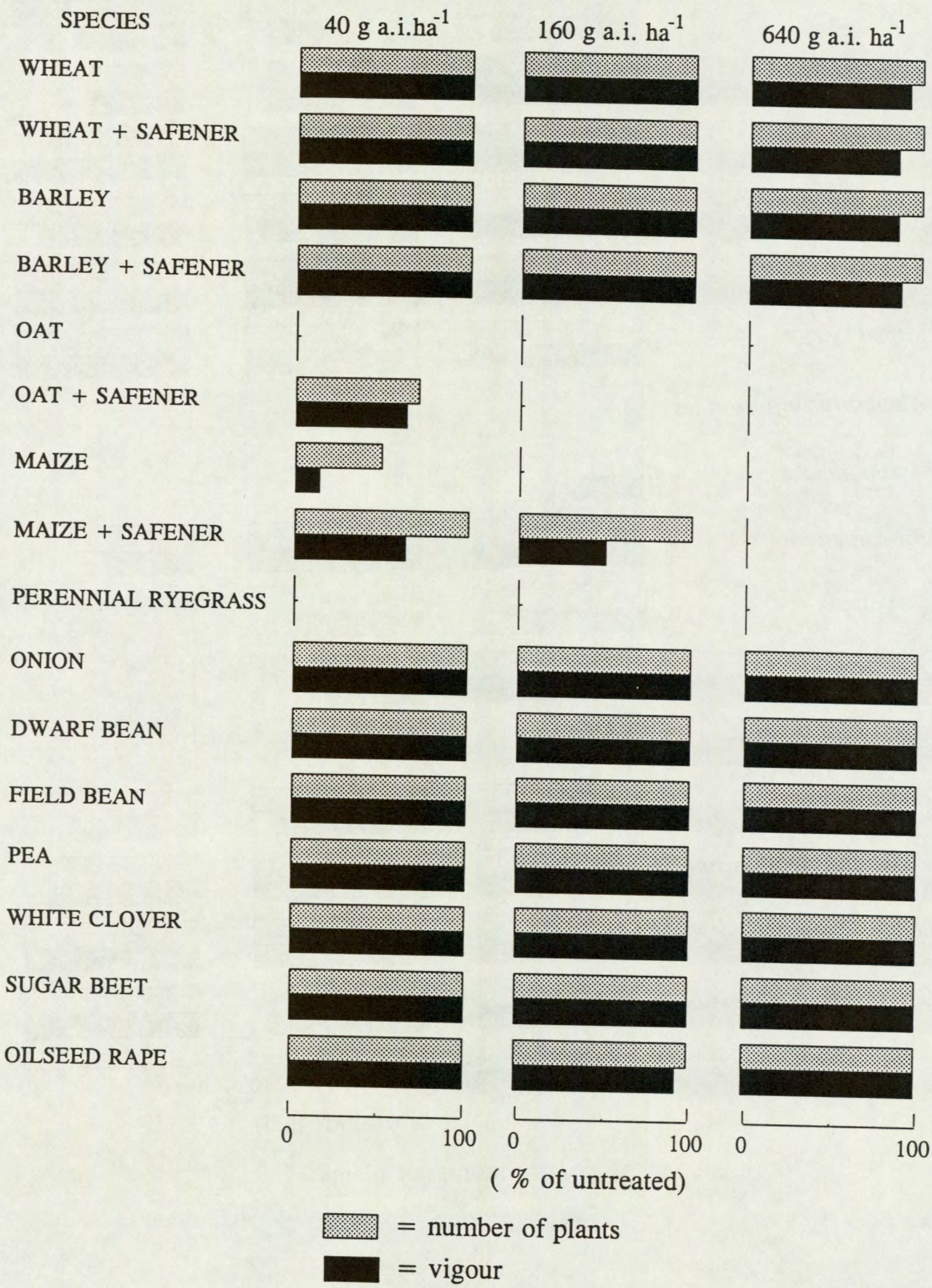


Figure 6 POST-EMERGENCE SELECTIVITY EXPERIMENT

Tralkoxydim (FD 4026)

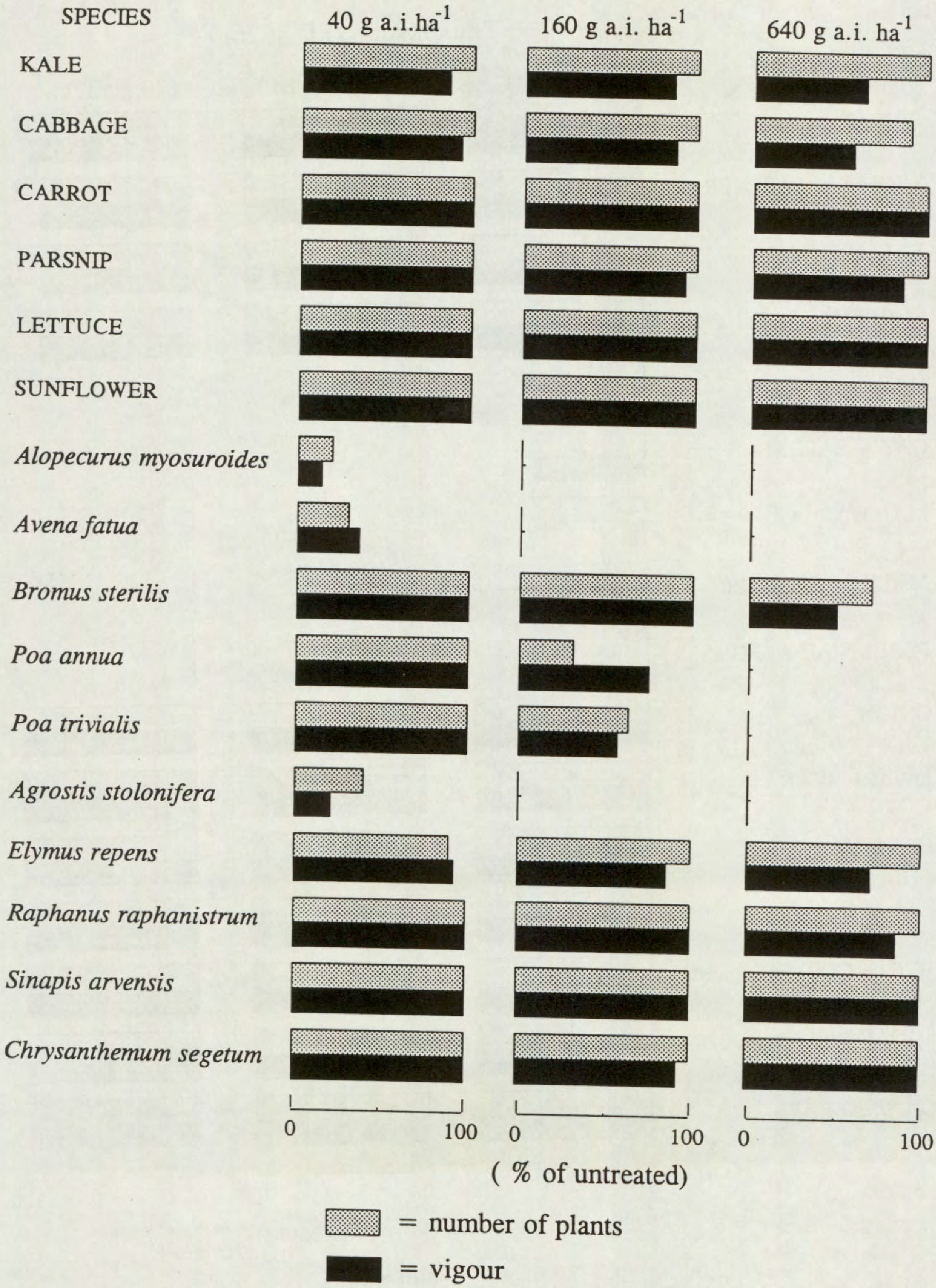


Figure 7 POST-EMERGENCE SELECTIVITY EXPERIMENT

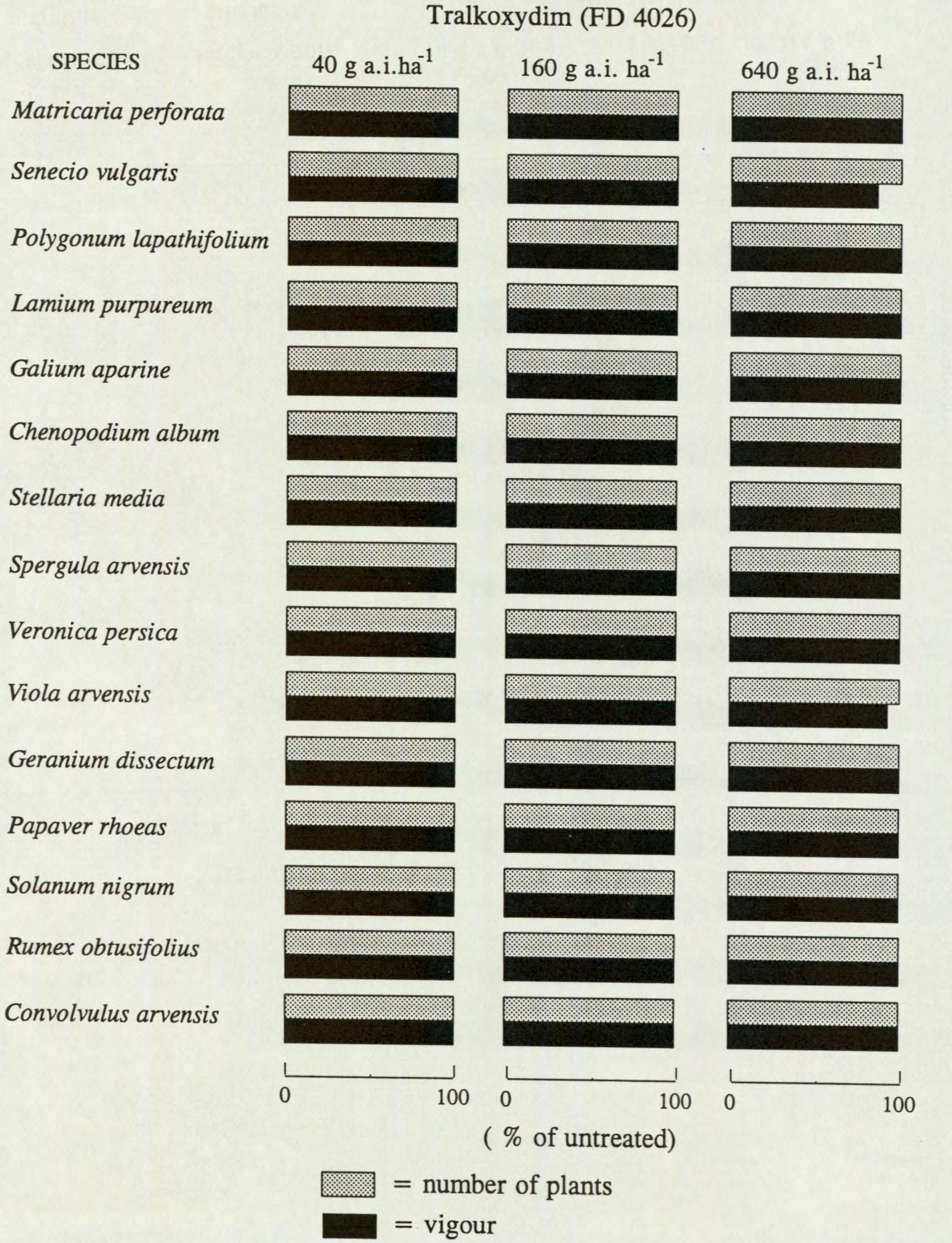
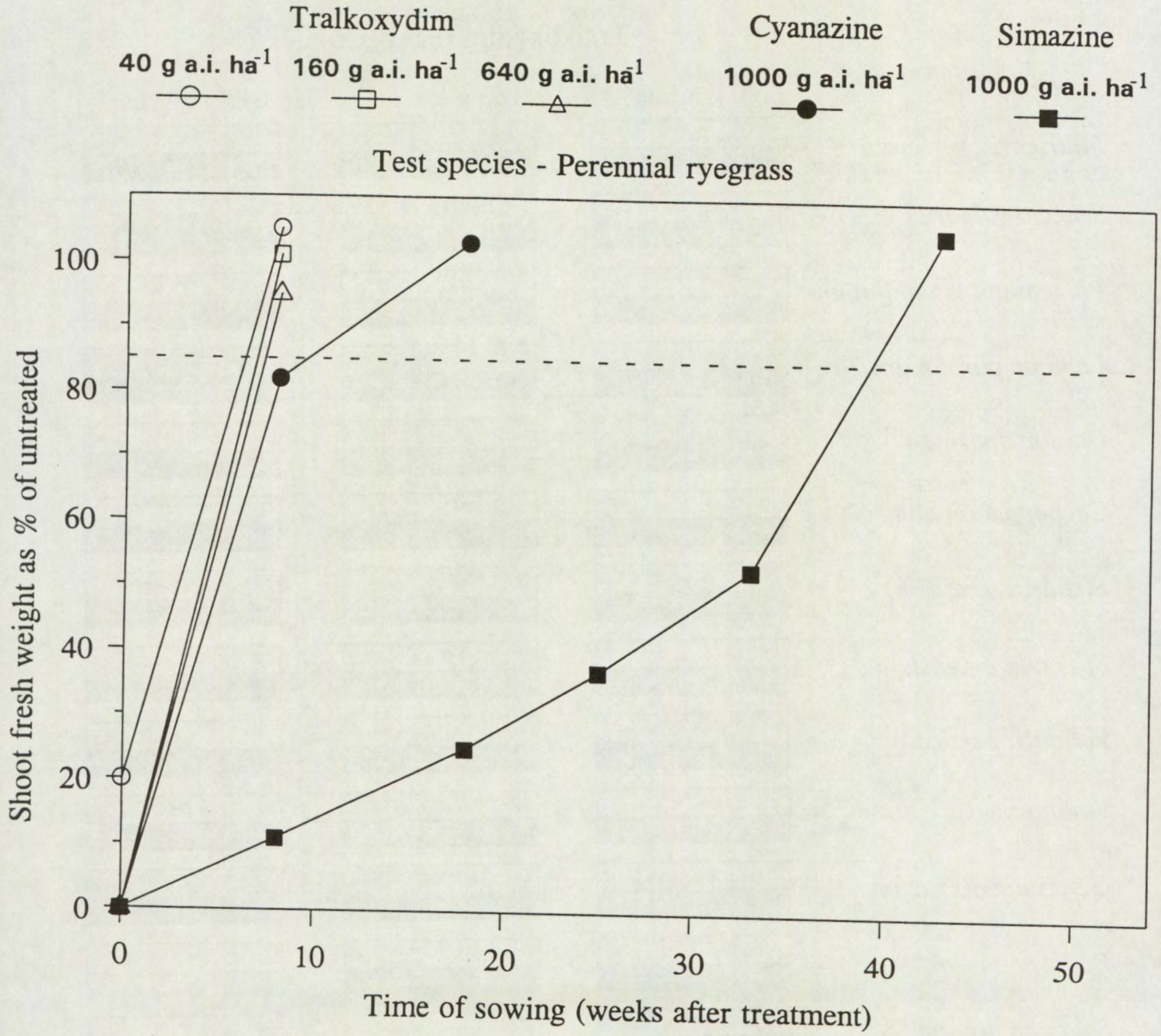


Figure 8 PERSISTENCE OF TRALKOXYDIM (FD 4026) COMPARED WITH CYANAZINE AND SIMAZINE



5. DISCUSSION

Our initial experiment showed that tralkoxydim can exhibit activity on susceptible species when applied either pre- or post-emergence. Post-emergence treatments can have a considerable effect when applied to the soil only as well as on to the foliage only, as shown by its activity against Lolium perenne and Avena fatua. Similar activity was reported by Nilsson (1991). This soil activity may have been exaggerated because plants had regular irrigation which maintained a high level of soil moisture within the pots. However, this does suggest that a combination of shoot and root uptake may give the most effective weed control from post-emergence treatments. Therefore, spraying when the soil has a high soil moisture content would probably be advantageous for maximum activity of this herbicide.

Results from the pre-emergence selectivity experiment showed that tralkoxydim is active on some species when applied pre-emergence. The grass weeds, Alopecurus myosuroides and Poa trivialis, were effectively controlled by 160 g a.i. ha^{-1} of tralkoxydim, a dose well tolerated by all the crops tested, except perennial ryegrass, which was particularly sensitive to tralkoxydim. Surprisingly, Avena fatua, a species sensitive to post-emergence treatments of tralkoxydim at 150 g a.i. ha^{-1} in the activity experiment, required 640 g a.i. ha^{-1} of tralkoxydim for effective pre-emergence control. At this dose, a few dicotyledonous crop and annual weed species also showed some reduction of growth or survivor-numbers, particularly Chrysanthemum segetum, Lamium purpureum and Viola arvensis. However, at recommended post-emergence doses (150-300 g a.i. ha^{-1}), and allowing for the increased soil activity of herbicides usually associated with pot experiments, any damage to germinating dicotyledonous weed species from pre-emergence activity of tralkoxydim in field situations after a post-emergence treatment would appear to be unlikely.

The survival and vigour of cultivated oat was severely reduced by tralkoxydim at 640 g a.i. ha^{-1}, similar to that of wild oat (Avena fatua), but growth of oat plants from seed dressed with NA safener was only slightly suppressed; this safening effect warrants further study.

The post-emergence selectivity experiment showed that tralkoxydim at 160 g a.i. ha^{-1} was very active against the intractable grass weeds, Alopecurus myosuroides and Avena fatua, while wheat, barley and all the dicotyledonous crop species tested were tolerant. Other problem grass weeds, such as Bromus sterilis and Elymus repens, and all dicotyledonous weeds showed appreciable tolerance. Although there was some suppression of Poa annua, this has not been found in field trials (Canning et al., 1993). The sensitivity of Lolium perenne showed the potential of tralkoxydim to control other Lolium spp., such as Lolium multiflorum, occuring as weeds in the UK. This agrees with previous reports of tralkoxydim activity on these species (Warner et al., 1987). The short period of soil persistence of active tralkoxydim residues, indicated in this experiment, would be advantageous in preventing residual phytotoxicity problems in following crops, such as oat or ryegrass, but any pre-emergence activity against sensitive grass weeds germinating after treatment will be very short-lived. These results indicate that, as a herbicide for control of temperate weed species, tralkoxydim activity is limited to certain important intractable grass weeds. Therefore, this herbicide will often be employed in a programme of mixtures or sequences with other herbicides to achieve broad-spectrum weed control. However, recent work has shown that mixtures with some sulfonylurea or hormone-type herbicides are antagonistic to tralkoxydim activity (De-Villiers & Du-Toil, 1992; Devine & Rashid, 1993; Harker & Blackshaw, 1991; Salembier, 1990 and Yaduraju et al., 1992). Applying tralkoxydim in sequence, instead of tank-mixing, can overcome this problem with some herbicides (Jensen & Caseley, 1990) but this would have the disadvantage of increasing the number of spraying operations and cost. Therefore, careful selection of herbicide partners for tralkoxydim must be made if tank-mixtures are to be effective.

Another problem that users of certain herbicides should be aware of is the increasing occurrence of herbicide-resistance. Tralkoxydim belongs to a class of herbicides called cyclohexanediones, commonly known as the 'dims', to which some grass weeds in various parts of the world, normally susceptible to these herbicides, have developed resistant populations (Heap et al., 1993; Marles et al., 1993; Mansooji et al., 1992 and Tardif et al., 1993). In the UK, several populations of Alopecurus myosuroides have been identified as being resistant to some 'dim' herbicides, including tralkoxydim, and also to some aryloxyphenoxypropionates, commonly known as the 'fop' herbicides e.g. diclofop-methyl (Clarke & Moss, 1989; Clarke & Moss,1991). A Lolium multiflorum population has also shown indications of resistance to tralkoxydim (Moss, 1993), and, more recently, three populations of Avena ludoviciana (winter wild oat) were confirmed as being resistant to fenoxprop-ethyl, diclofop-methyl and fluazifop-P-butyl, while one of these populations showed clear resistance to tralkoxydim (Moss et al., 1994).

The specific nature of tralkoxydim activity against certain pernicious grass weeds, and the tolerance of many crop and wild herb species, suggests that tralkoxydim is a potential candidate for application in situations of restricted herbicide use. Work by Canning et al.(1993) showed useful control of the aggressive grass weeds, Alopecurus myosuroides and Avena fatua, in conservation headlands where annual dicotyledonous species are encouraged as food sources for gamebirds and insects. Other situations which are governed by prescriptions for limited herbicide use, e.g. set-aside or Environmently Sensitive Areas, may also benefit from the specific activity and short soil persistence offered by this herbicide.

The increasingly popular practice of leaving areas of semi-natural habitat around field margins, using cultivated boundary strips which either regenerate naturally or are sown with perennial grass/wild herb mixtures (Marshall et al., 1994), may also benefit from the application of herbicides such as tralkoxydim for control of specific aggressive weeds

(Boatman, 1993; Marshall & Nowkowski, 1994). This is particularly important in the early stages of establishment to encourage growth and spread of young plants. Further studies on the effects of tralkoxydim on non-target grass species would be useful to determine its potential as a management aid in these field boundary strips.

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APPENDICES

APPENDIX 1. Species Information for Activity Experiment

Species	Cultivar (source)	N° of seeds or plants pot^{-1} Pre-em.	N° of seeds or plants pot^{-1} Post-em.	Depth of planting (cm)	Growth stage of untreated plants at:- Spraying Post-em.	Assessment Pre-em.	Assessment Post-em.
Dwarf bean (Phaseolus vulgaris)	The Prince (Finney Lock)	3	2	2	1 trifoliate expanding	3 trifoliates flowering	3 trifoliates flowering
Kale (Brassica oleraceae acephala)	Marrowstem (Finney Lock)	10	5	0.5	2.5 leaves	4 leaves	6 leaves
Polygonum amphibium (amphibious bistort)	WRO[a] Clone 1	6	5	1.5	3-4 leaves	12 leaves	11 leaves
Perennial ryegrass (Lolium perenne)	Melle (British seedhouses)	12	8	0.5	3 leaves	5 leaves, 7 tillers	5 leaves, 5 tillers
Avena fatua (wild oat)	LARS[b]	12	5	1	3 leaves	6 leaves	7 leaves, 2 tillers
Elymus repens (common couch)	WRO[a] Clone 31	6	4	1	3 leaves	6 leaves, 1 tillers	8 leaves, 2 tillers

[a] WRO denotes rhizome collected from stockbed plants originally propagated at the Weed Research Oganization, Oxford, but now maintained at Long Ashton Reseach Station. [b] LARS denotes seed collected from stockbed plants propagated and maintained at Long Ashton Research Station.

APPENDIX 2. Species Information for Pre-emergence Experiment

Species	Cultivar or source	No. pot^{-1}	Depth of planting (cm)	Growth stage of untreated controls at assessment
Wheat (*Triticum aestivum*)	Avalon	8	1	5 leaves, 1 tiller
Wheat + NA safener	Avalon	8	1	5 leaves, 1 tiller
Barley (*Hordeum vulgare*)	Igri	8	1	5 leaves, 1 tiller
Barley + NA safener	Igri	8	1	5 leaves, 1 tiller
Oat (*Avena sativa*)	Peniarth	8	1	5 leaves
Oat + NA safener	Peniarth	8	1	5 leaves
Maize (*Zea mays*)	LG 11	4	2	5 leaves
Maize + NA safener	LG 11	4	2	5 leaves
Perennial ryegrass (*Lolium perenne*)	Melle	12	0.5	4 leaves, 2 tillers
Onion (*Allium cepa*)	White Lisbon	15	0.5	4 leaves
Dwarf bean (*Phaseolus vulgaris*)	The Prince	3	2	3 trifoliates
Field bean (*Vicia fabia*)	Maris Bead	4	1.5	5 leaves
Pea (*Pisum sativum*)	Meteor	4	1.5	6 leaves
White clover (*Trifolium repens*)	Huia	15	0.25	5 trifoliates
Sugar beet (*Beta vulgaris*)	Samson	8	1	4 leaves
Oilseed rape (*Brassica napus oleifera*)	Jet Neuf	12	0.5	4 leaves
Kale (*Brassica oleracea acephala*)	Marrowstem	12	0.5	4 leaves

APPENDIX 2. (cont'd) Species Information for Pre-emergence Experiment

Species	Cultivar or source	No. pot^{-1}	Depth of planting (cm)	Growth stage of untreated controls at assessment
Swede (*Brassica napus*)	Marian	12	0.5	4 leaves
Carrot (*Daucus carota*)	Chentenay Red Cored	12	0.5	4 leaves
Lettuce (*Lactuca sativa*)	Webbs Wonderful	15	0.5	5 leaves
Sunflower (*Helianthus annuus*)	Frankasol	7	1.5	2 pairs leaves
Alopecurus myosuroides (Blackgrass)	Herbiseed	20	0.25	4 leaves, 2 tillers
Avena fatua (Wild oat)	LARS/NP	10	1	5 leaves
Bromus sterilis (Barren brome)	Herbiseed	8	1	5 leaves, 2 tillers
Festuca rubra (Red fescue)	Herbiseed	20	0.5	4 leaves, 3 tillers
Poa annua (Annual meadow-grass)	Herbiseed	20	0.25	5 leaves, 2 tillers
Poa trivialis (Rough meadow-grass)	Herbiseed	16	0.25	4 leaves, 2 tillers
Elymus repens (Common couch)	LARS (Stockbed)	6	1	4 leaves, 1 tiller
Raphanus rapanistrum (Wild radish)	Herbiseed	12	0.5	7 leaves, flower buds
Sinapis arvensis (Charlock)	B & S	15	0.5	6 leaves, flowering
Chrysanthemum segetum (Corn marigold)	B & S	25	Surface	6 leaves
Matricaria perforata (Scentless mayweed)	Herbiseed	25	Surface	7 leaves
Senecio vulgaris (Groundsel)	Herbiseed	15	Surface	8 leaves, flower buds
Polygonum lapathifolium (Pale persicaria)	Herbiseed	20	0.5	4 leaves

APPENDIX 2. (cont'd) Species Information for Pre-emergence Experiment

Species	Cultivar or source	No. pot^{-1}	Depth of planting (cm)	Growth stage of untreated controls at assessment
Fallopia convolvulus (Black bindweed)	Herbiseed	20	0.5	5 leaves, axillaries
Lamium purpureum (Red dead-nettle)	Herbiseed	20	0.5	3 pairs leaves, axillaries
Galium aparine (Cleavers)	Herbiseed	16	0.5	4 whorls on stems, + axillaries
Chenopodium album (Fat hen)	Herbiseed	15	0.25	6 leaves
Stellaria media (Common chickweed)	Herbiseed	20	0.25	4 pairs leaves on stems, + axillaries
Viola arvensis (Common field speedwell)	Herbiseed	25	0.25	4 leaves
Veronica persica (Field pansy)	Herbiseed	20	0.25	5 pairs leaves, + axillaries
Geranium dissectum (Cut-leaved cranesbill)	Herbiseed	10	0.5	5 leaves
Solanum nigrum (Black nightshade)	Herbiseed	15	Surface	6 leaves
Rumex obtusifolius (Broad-leaved dock)	Herbiseed	15	0.25	4 leaves
Cirsium arvense (Creeping thistle)	LARS (Stockbed)	6	1	5 leaves
Convolvulus arvensis (Field bindweed)	Herbiseed	20	0.5	5 leaves

APPENDIX 3. Species information for Post-emergence Experiment

Species	Cultivar or source	No. plants pot^{-1}	Growth stage of untreated controls: At spraying	At assessment
Wheat (*Triticum aestivum*)	Avalon	5	3 leaves	7 leaves, 4 tillers
Wheat + NA safener	Avalon	5	3 leaves	7 leaves, 4 tillers
Barley (*Hordeum vulgare*)	Igri	5	3 leaves	7 leaves, 5 tillers
Barley + NA safener	Igri	5	3 leaves	7 leaves, 5 tillers
Oat (*Avena sativa*)	Peniarth	5	3 leaves	6 leaves, 6 tillers
Oat + NA safener	Peniarth	5	3 leaves	6 leaves, 6 tillers
Maize (*Zea mays*)	LG 11	3	3 leaves	8 leaves
Maize + NA safener	LG 11	3	2.5 leaves	7 leaves
Perennial ryegrass (*Lolium perenne*)	Melle	8	3 leaves, 1 tiller	7 leaves, 10 tillers
Onion (*Allium cepa*)	White Lisbon	5	3 leaves	6 leaves
Dwarf bean (*Phaseolus vulgaris*)	The Prince	2	1 trifoliate	6 trifoliates, flower buds
Field bean (*Vicia faba*)	Maris Bead	3	3 leaves	15 leaves, flowering
Pea (*Pisum sativum*)	Meteor	3	4 leaves	9 leaves
White clover (*Trifolium repens*)	Huia	5	3 trifoliates	4 stolons, 4-7 trifoliates on stolons
Sugar beet (*Beta vulgaris*)	Samson	5	4 leaves	12 leaves
Oilseed rape (*Brassica napus oleifera*)	Jet Neuf	5	3 leaves	7 leaves
Kale (*Brassica oleracea acephala*)	Marrowstem	5	3 leaves	7 leaves
Cabbage (*Brassica oleracea capitata*)	Golden acre	5	3 leaves	12 leaves

APPENDIX 3. (cont'd) Species information for Post-emergence Experiment

Species	Cultivar or source	No. plants pot^{-1}	Growth stage of untreated controls: At spraying	Growth stage of untreated controls: At assessment
Carrot (*Daucus carota*)	Chentenay Red Cored	5	3 leaves	7 leaves
Parsnip (*Pastinaca sativa*)	White Gem	3	2 leaves	5 leaves
Lettuce (*Lactuca sativa*)	Webbs Wonderful	5	4 leaves	10 leaves
Sunflower (*Helianthus annuus*)	Frankasol	3	2 pairs leaves	5 pairs leaves
Alopecurus myosuroides (Blackgrass)	Herbiseed	5	3 leaves, 1 tiller	12 tillers
Avena fatua (Wild oat)	LARS/NP	5	2.5 leaves, 1 tiller	6 leaves, 2 tillers
Bromus sterilis (Barren brome)	Herbiseed	5	2.5 leaves	8 tillers
Poa annua (Annual meadow-grass)	Herbiseed	8	3 leaves, 1 tillers	16 tillers
Poa trivialis (Rough meadow-grass)	Herbiseed	8	3 leaves, 1 tillers	20 tillers
Agrostis stolonifera (Creeping bent)	Herbiseed	5	3 leaves, 4 tillers	15 tillers
Elymus repens (Common couch)	LARS (Stockbed)	5	3 leaves,	5 leaves, 3 tillers
Raphanus raphanistrum (Wild radish)	Herbiseed	3	3 leaves	7 leaves, flowering
Sinapis arvensis (Charlock)	Herbiseed	5	3.5 leaves	7 leaves, flowered
Chrysanthemum segetum (Corn marigold)	Herbiseed	4	4 leaves,	17 leaves, flowering
Matricaria perforata (Scentless mayweed)	Herbiseed	5	4 leaves	15 leaves, axillaries, flowering
Senecio vulgaris (Groundsel)	Herbiseed	5	3 leaves	8 leaves, flowering

APPENDIX 3. (cont'd) Species information for Post-emergence Experiment

Species	Cultivar or source	No. plants pot^{-1}	Growth stage of untreated controls: At spraying	At assessment
Polygonum lapathifolium (Pale persicaria)	Herbiseed	5	4 leaves	11 leaves, flowering
Lamium purpureum (Red dead-nettle)	Herbiseed	5	2 pairs leaves	7 pairs leaves, axillaries, flowering
Galium aparine (Cleavers)	Herbiseed	5	3 whorls	12 whorls on 6 main branches, axillaries
Chenopodium album (Fat hen)	Herbiseed	5	4 leaves	12 leaves, flowering,
Stellaria media (Common chickweed)	Herbiseed	5	3 pairs leaves,	9 pairs leaves on branches, flowering
Spergula arvensis (Corn spurrey)	Herbiseed	5	2 whorls	7 whorls, axillaries, flowering
Veronica persica (Common field speedwell)	Herbiseed	4	3 pairs leaves	7 pairs leaves, axillaries
Viola arvensis (Field pansy)	Herbiseed	4	4 leaves	9 leaves, axillaries, flowering
Geranium dissectum (Cut-leaved cranesbill)	Herbiseed	5	3 leaves	16 leaves
Papaver rhoeas (Common poppy)	Herbiseed	5	4 leaves	11 leaves, axillaries, flowering
Solanum nigrum (Black nightshade)	Herbiseed	5	3 leaves	7 leaves, axillaries, flowering
Rumex obtusifolius (Broad-leaved dock)	Herbiseed	5	3 leaves	5 leaves
Convolvulus arvensis (Field bindweed)	Herbiseed	5	3 leaves	9 leaves

APPENDIX 4 Addresses of UK seed suppliers

B & S Weed Seed Suppliers
Little Orchard
Main Street
Whatton in the Vale
Nottingham
England
NG13 9EP

British Seedhouses
Portview Road
Avonmouth
Bristol
England

Finney Lock Seeds Ltd
Avenue Road
Witham
Essex
England
CN18 2DX

Herbiseed
The Nurseries
Billingbear Park
Wokingham RG11 5RY
England
RG11 5RY

APPENDIX 5

ABBREVIATIONS

acid equivalent	a.e.	minute	min
active ingredient	a.i.	more than	>
approximately equal to	≈	organic matter	o.m.
centimetre	cm	page	p.
cultivar (s)	cv.	pages	pp.
degree centigrade	°C	part per million	ppm
emulsifiable concentrate	EC	per	$^{-1}$
equal to	=	percent(age)	%
gramme	g	plus or minus	±
hectare	ha	post-emergence	post-em
hour	h	pre-emergence	pre-em
hydrogen ion concentration	pH	relative humidity	r.h.
kilogramme	kg	second	s
less than	<	soluble liquid	SL
litre	l.	species (singular)	sp.
maximum	max	species (plural)	spp.
metre	m	sub-species	ssp.
micrometre	μm	temperature	temp
milligramme	mg	<u>varietas</u>	var.
millilitre	ml	volume per volume	v/v
millimetre	mm	water dispersible granule	WG
minimum	min.	wettable powder	WP

APPENDIX 6

CROP AND ENVIRONMENTAL SCIENCES DEPARTMENT
IACR, LONG ASHTON RESEARCH STATION

TECHNICAL REPORTS

(Price includes surface mail; airmail £2.00 extra)
(* denotes Reports now out of print)

6. The botany, ecology, agronomy and control of Poa trivialis L. rough-stalked meadow-grass. November 1966. G P Allen. Price £0.25

7. Flame cultivation experiments 1965. October 1966. G W Ivens - Price £0.25

8. The development of selective herbicides for kale in the United Kingdom. 2. The methylthiotriazines. Price £0.25

10. The liverwort, Marchantia polymorpha L. as a weed problem in horticulture; its extent and control. July 1968. I E Henson. Price £0.25

11. Raising plants for herbicide evaluation; a comparison of compost types. July 1968. I E Henson. Price £0.25

12.* Studies on the regeneration of perennial weeds in the glasshouse; I. Temperate species. May 1969. I E Henson. Price £0.25

13. Changes in the germination capacity of three Polygonum species following low temperature moist storage. May 1969. I E Henson. Price £0.25

14. Studies on the regeneration of perennial weeds in the glasshouse. II. Tropical species. May 1970. I E Henson. Price £0.25

15. Methods of analysis for herbicide residues. February 1977. (second edition). Price £5.75

16. Report on a joint survey of the presence of wild oat seeds in cereal seed drills in the United Kingdom during spring 1970. November 1970. J G Elliott and P J Attwood. Price £0.25

17. The pre-emergence selectivity of some newly developed herbicides, Orga 3045 (in comparison with dalapon), haloxydine (PP 493), HZ 52.112, pronamide (RH 315) and R 12001. January 1971. W G Richardson, C Parker and K Holly. Price £0.25

18. A survey from the roadside of the state of post-harvest operations in Oxfordshire in 1971. A Philipson. Price £0.25

19.* The pre-emergence selectivity of some recently developed herbicides in jute, kenaf and sesamum, and their activity against Oxalis latifolia. December 1971. M L Dean and C Parker. Price £0.25

20.* A survey of cereal husbandry and weed control in three regions of England. July 1972. A Philipson, T W Cox and J G Elliot. Price £0.35

21. An automatic punching counter. November 1972. R C Simmonds. Price £0.30

22. The pre-emergence selectivity of some newly developed herbicides: bentazon, BAS 373OH, metflurazone, SAN 9789, HER 52.123, U 27,267. December 1972. W G Richardson and M L Dean. Price £0.25

23. A survey of the presence of wild oats and blackgrass in parts of the United Kingdom during summer 1972. A Philipson. Price £0.25

24. The conduct of field experiments at the Weed Research Organization. February 1973. J G Elliott, J Holroyd and T O Robson. Price £1.25

25. The pre-emergence selectivity of some recently developed herbicides: lenacil, RU 12068, metribuzin, cyprazine, EMD-IT 5914 and benthiocarb. August 1973 W G Richardson and M L Dean. Price £1.75

26. The post-emergence selectivity of some recently developed herbicides: bentazone, EMD-IT 6412, cyprazine, metribuzin, chlornitrofen, glyphosate, MC 4379, Chlorfenprop-methyl. October 1973. W G Richardson and M L Dean. Price £3.31

27. Selectivity of benzene sulphonyl carbamate herbicides between various pasture grasses and clover. October 1973. A M Blair. Price £1.05

28. The post-emergence selectivity of eight herbicides between pasture grasses: RP 17623, HOE 701, BAS 3790, metoxuron, RU 12068, cyprazine, MC 4379, metribuzin. October 1973. A M Blair. Price £1.00

29.* The pre-emergence selectivity between pasture grasses of twelve herbicides: haloxydine, pronamide, NC 8438, Orga 3045, chlortoluron, metoxuron, dicamba, isopropalin, carbetamide, MC 4379, MBR 8251 and EMD-IT 5914. November 1973. A M Blair. Price £1.30

30. Herbicides for the control of the broad-leaved dock (Rumex obtusifolius L.). November 1973. A M Blair and J Holroyd. Price £1.06

31. Factors affecting the selectivity of six soil acting herbicides against Cyperus rotundus. February 1974. M L Dean and C Parker. Price £1.10

32. The activity and post-emergence selectivity of some recently developed herbicides: oxadizon, U-29,722, U-27,658, metflurazone, norflurazone, AC 50-191, AC 84,777 and iprymidam. June 1974. W G Richardson and M L Dean. Price £3.62

33. A permanent automatic weather station using digital integrators. September 1974. R C Simmonds. Price £0.63

34. The activity and pre-emergence selectivity of some recently developed herbicides: trifluralin, ispropalin, oryzalin, dinitramine, bifenox and perfluidone. November 1974. W G Richardson and M L Dean. Price £2.50

35. A survey of aquatic weed control methods used by Internal Drainage Boards, 1973. January 1975. T O Robson. Price £1.39

36. The activity and pre-emergence selectivity of some recently developed herbicides: Bayer 94871, tebuthiuron, AC 92553. March 1975. W G Richardson and M L Dean. Price £1.54

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