Clopyralid Effects on Shoot Emergence, Root Biomass, and Secondary Shoot Regrowth Potential of Canada Thistle (*Cirsium arvense*)[1,2]

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Abstract. The root fresh weight of intact Canada thistle plants was greater than that of decapitated plants 2 months following soil surface treatment with clopyralid at 140 g ai/ha. Nevertheless, secondary shoot regrowth potential was reduced to the same extent for both intact and decapitated plants after clopyralid treatment. Soil-applied clopyralid did not reduce root biomass as much as it reduced secondary shoot regrowth potential from adventitious root buds. Increasing the clopyralid rate from 11 to 1120 g/ha progressively reduced the total number of emerged shoots more than root fresh weight 2 months after treatment of decapitated Canada thistle. Increasing the clopyralid rate also reduced the regrowth potential of secondary shoots from root buds proportionately more than it reduced root biomass. Secondary shoots emerging through a surface layer of soil treated with clopyralid at 140 g/ha absorbed phytotoxic amounts of clopyralid. Secondary shoot numbers were not reduced after emerging through an activated charcoal layer into herbicide-treated soil, but they were deformed and their dry weight was reduced as was later secondary shoot regrowth potential. Nomenclature: Canada thistle, *Cirsium arvense* (L.) Scop. #[4] CIRAR 'integrifolium' Wimm. and Grab.; clopyralid, 3,6-dichloro-2-pyridinecarboxylic acid.

Additional index words. Herbicide, adventitious root bud, perennial weed.

INTRODUCTION

Canada thistle is widely distributed in the northern United States and Canada (16, 18, 19, 22). It is a growing concern on no-till farmland, especially in spring-sown cereals, because it is a perennial weed with an extensive, spreading root system (2, 15, 16, 17, 29). New plants or secondary shoots arise from adventitious root buds and help propagate this weed vegetatively after it is established (13, 14, 15).

Recently clopyralid was registered in the United States as a prepackaged tank mix with 2,4-D [(2,4-dichlorophenoxy) acetic acid] and was formulated as Curtail® for broadleaf

weed control, including Canada thistle in spring wheat (*Triticum aestivum* L.). Foliar-applied clopyralid alone controlled Canada thistle at 100 to 200 g/ha in the greenhouse (11, 21, 24, 26, 32) and at higher rates (1, 31) in fields of various crops. Clopyralid applied alone was nonphytotoxic to barley (*Hordeum vulgare* L.) (20, 26), sugarbeets (*Beta vulgaris* L.) (10, 11, 21), rapeseed (*Brassica napus* L.) (5, 20, 24, 28), corn (*Zea mays* L.) (4, 5, 21, 27), flax (*Linum usitatissimum* L.) (5, 27), oats (*Avena sativa* L.) (4), and wheat (4, 5, 20).

Clopyralid was translocated from the shoot to the fibrous roots of small Canada thistle plants (7, 31, 32) and in larger vegetative and flowering plants with thickened propagative roots having root buds (25). Clopyralid inhibited secondary shoot growth of Canada thistle after uptake from the soil (12). Small potted plants with only 8 to 10 leaves were damaged more by foliar plus soil treatment with clopyralid at 25 to 200 g/ha than by foliar treatment alone. However, soil surface-applied clopyralid was not included as a treatment for comparison in this experiment. There are no published reports of ^{14}C-clopyralid transport from the roots to the shoots of Canada thistle, although this is likely to occur.

The objectives of this research were to: a) quantify the effect of foliar- and soil-applied clopyralid on secondary shoot emergence from soil, root biomass, and secondary shoot regrowth potential of large Canada thistle with well-developed roots and numerous root buds; b) determine whether decapitating Canada thistle shoots modified the root systems' regrowth potential after soil surface treatment with clopyralid; c) characterize the response of well-established Canada thistle to various rates of soil surface-applied clopyralid following decapitation; and d) determine if new secondary shoots of decapitated Canada thistle growing through clopyralid-treated soil would be damaged without root exposure to the herbicide.

These biological studies were conducted in preparation for future studies of ^{14}C-clopyralid translocation in Canada thistle. While ^{14}C-clopyralid translocation has been studied in small Canada thistle with fibrous roots having few or no root buds (7, 31, 32) and larger perennial plants (25), ^{14}C-clopyralid transport has not been related to the biological response of Canada thistle roots to the herbicide.

MATERIALS AND METHODS

General methods. Experiments were conducted in a greenhouse from September 1986 to August 1987. Canada thistle plants (23) were grown from 4- to 8-cm-long root cuttings (8) placed for 1.5 to 2 months in 21- by 30- by 8-cm trays containing fine vermiculite. The vermiculite was top watered with one-third strength nutrient solution (3) or tapwater.

Uniform plants with five to seven leaves were transplanted to 1-L pots (16.5-cm diam by 18-cm height) containing a greenhouse potting soil mix (73% sand, 19% silt, 8% clay, and 3.6% organic matter, at a pH of 7.9). A slow-release fertilizer containing $N:P_2O_5:K_2O$ (18:6:12) was added to the potting soil at 20 g/pot at the time of transplanting. Plants were grown for 2 to 2.5 additional months before clopyralid treatment. Plants were selected for uniformity based on plant height, leaf node number, and flowering stage. Leaves less than 3 to 4 mm in length were not counted. Morphological characteristics rather than chronological age were the basis for determining stage of plant development because plants develop at different rates at different times of the year. A 14-h day length was achieved by supplementing sunlight with fluorescent lights, which provided 125 to 130 $\mu E \cdot m^{-2} \cdot s^{-1}$ (20 watts·m^{-2}) at the canopy height, 42 to 60 cm below the fluorescent light bulbs. Relative humidity ranged between 30 and 85%. The greenhouse was normally maintained at 25 C in the day and 20 C at night. Occasionally, the temperature fluctuated between extremes of 20 and 32 C in the day, and 16 and 23 C at night. Plants were top watered as needed because the roots decayed when sub-irrigated for extended periods of time. Plants were not root bound at the time of treatment in this or previous studies (6, 8, 9). Thickened roots did not completely fill the pot although some roots wound around the bottom of the pot.

Formulated clopyralid[5] was sprayed on Canada thistle shoots in one pass with a movable-nozzle hooded sprayer traveling at 0.77 km/h. A flat-fan nozzle[6] supplied 234 L/ha at 179 kPa.

Plants were harvested 2 months after spray treatment. Treated shoots and newly emerged shoots were severed at the soil surface and discarded. Nearly all newly emerged shoots arose from root buds, not the base of the cut shoot. Roots were unearthed, washed free of soil with tapwater, cut into 5-cm segments, and stored in darkness at 0 to 5 C for 0 to 4 days during harvest. The root segments were replanted 1 cm deep in trays (12 by 16 by 5.5 cm, 1 L) filled with fine vermiculite. In order to measure secondary shoot regrowth potential, the unearthed root system was segmented to break apical dominance and promote secondary shoot formation from elongating adventitious root buds. Secondary shoots that had emerged above the vermiculite surface were counted 5 weeks after segmenting and planting. Secondary shoots from adventitious root buds were severed at the junction between the secondary shoot and the original root segment, washed free of vermiculite, dried at 70 C for 2 days, and weighed. Measurements of secondary shoot number and dry weight indicate plant vigor but may underestimate total adventitious root bud number (8).

All experiments were arranged as a completely randomized design with four to eight replicate pots/treatment. Data were subjected to analysis of variance (ANOVA), and treatment means were separated with Duncan's multiple range test at P = 0.05, where appropriate (30). All experiments were conducted twice (trials 1 and 2), and results were combined where no trial by treatment interaction occurred.

Effect of site of treatment and decapitation. The treatments were: a) untreated controls, b) foliar-applied clopyralid plus surfactant[7] (principal agent: alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol; 90%) at 0.25% (v/v), c) soil surface-applied clopyralid, d) foliar plus soil-applied clopyralid, e) decapitated controls, and f) decapitated, soil surface-applied clopyralid. Clopyralid was applied at 140 g/ha. There were six plants/treatment. For foliar treatments, the soil surface was covered with 3 cm of vermiculite before spraying and it was removed after the spray had dried on the foliage. Clopyralid was applied as a 10-ml drench for soil-surface treatment alone. Shoots of decapitated plants were cut off at the soil surface.

Plants were 133 ± 3- and 127 ± 3-cm (mean ± standard deviation) tall and were flowering at the time of treatment in trials 1 and 2, respectively. Plants in trials 1 and 2 had 39 ± 2 and 35 ± 3 leaves, 10 ± 1 and 9 ± 2 flowering branches, and root fresh weights of 29.75 ± 3.11 g and 35.29 ± 2.5 g, respectively.

Eight weeks after treatment, the number of shoots emerging through the soil surface and the root fresh weights were determined. Secondary shoots emerging from segmented roots grown in vermiculite were counted 5 weeks after root segmentation.

Dose response. All plants were decapitated at the soil surface before they were sprayed with clopyralid at 0, 11, 33, 67, 140, 280, 560, 840, and 1120 g/ha. There were four pots/treatment. Eight weeks after treatment, the number and dry weight of emerged shoots were determined. Root fresh weight, secondary shoot numbers, and dry weight were determined as described previously. All plants were flowering and were 146 ± 2 and 123 ± 2 cm tall in trials 1 and 2, respectively. There were 48 ± 3 and 40 ± 1 leaves/plant and roots weighed 45.36 ± 2.11 and 39.34 ± 3.11 g/plant in the respective trials.

Clopyralid phytotoxicity to emerging shoots. All plants were decapitated at the soil surface before the experiment was started. There were four treatments with eight potted plants each: a) control pots in which a 2.5-cm layer of additional soil was placed on the soil surface; b) charcoal layer pots in which a 6-mm layer of activated charcoal was placed on the soil surface before 2.5 cm of additional soil was added; and c) clopyralid-treated and d) clopyralid plus charcoal layer pots which were the same as a) and b), respectively, except that after 2.5 cm of additional soil was added to each pot, the new soil surface was sprayed with clopyralid at 140 g/ha. Eight weeks after treatment, the number and dry weight of emerged shoots/pot were determined. Root fresh weight, secondary shoot numbers, and dry weight also were determined as described previously. Plants were

127 ± 7 and 115 ± 3 cm tall in trials 1 and 2, respectively, and were flowering when the experiment was started.

RESULTS AND DISCUSSION

Effect of site of treatment and decapitation. New shoot growth became epinastic within 7 days after foliar clopyralid treatment. Following foliar or foliar plus soil treatment, all leaves became chlorotic, whereas only the newly expanding leaves became chlorotic following soil treatment alone. Newly emerged shoots of decapitated plants growing through clopyralid-treated soil became both epinastic and chlorotic. Sprayed shoots of foliar- or foliar plus soil-treated plants died within a month, whereas newly emerged shoots were green but stunted and deformed. Shoots of soil-treated intact plants were killed more slowly than the shoots following either foliar treatment. When 30-cm-tall flowering Canada thistle was sprayed with clopyralid at 100 to 200 g/ha in the field, shoot growth also was stopped and became distorted and chlorotic before shoots died (11). However, 80-cm-tall shoots were not controlled, in contrast to our greenhouse research with foliar-applied clopyralid at 140 g/ha.

Root damage from clopyralid in either field- or greenhouse-grown Canada thistle has not been described in the literature. At 2 months, roots of intact plants were darker brown and more brittle after either type of foliar clopyralid treatment than were the roots of untreated intact controls or soil-treated intact plants. Thickened propagative roots of foliar-treated intact plants were still firm and turgid, despite some loss of lateral roots. Loss of lateral roots also was noted following foliar treatment of Canada thistle with phytotoxic rates of glyphosate [N-(phosphonomethyl)glycine] (6), and chlorsulfuron {2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide} (8), or soil-applied chlorsulfuron (8, 9). Thickened propagative roots did not decay unevenly after clopyralid treatment as they did after foliar glyphosate treatment (6). Clopyralid did not increase the number of visible root buds in contrast to soil surface-applied chlorsufluron to intact or decapitated Canada thistle (9).

Two months following decapitation, 1.5- and 2.7-fold more shoots emerged from decapitated controls through the soil surface in trials 1 and 2, respectively, than from intact controls ($P \leqslant 0.0001$) (Table 1). All clopyralid treatments decreased new shoot emergence through the soil surface from intact plants. Foliar clopyralid treatment of intact plants reduced shoot emergence in both trials. Soil or foliar plus soil treatment significantly decreased new shoot emergence in trial 1, but only a nonstatistical trend was observed in trial 2. Although clopyralid reduced the total number of emerging shoots, those that emerged came up within 3 weeks. Perhaps these shoots were in the process of elongating at the time of treatment and did not receive a sufficient dose of clopyralid quickly enough to inhibit shoot emergence through the soil surface.

The root fresh weight of intact controls increased 2 months after the start of the experiment, whereas the root biomass of decapitated controls remained unchanged ($P \leqslant 0.0001$) (Table 1). Foliar- or foliar plus soil-applied clopyralid prevented root fresh weight accumulation of intact plants relative to controls at the start. In contrast, root fresh weight increased following soil application of clopyralid to intact plants, but not as much as for the intact controls. The root fresh weight of decapitated, soil surface-treated plants was less than that of decapitated controls after 2 months but no different than at the start. Apparently, foliar treatment of intact plants or soil treatment of decapitated plants with clopyralid prevented roots from growing and increasing their fresh weight. Root growth following soil treatment with clopyralid was less inhibited with intact plants than with topped plants, perhaps due to the continual supply of photoassimilates to the roots by intact plants.

When roots were segmented at harvest to release apical dominance and promote secondary shoot outgrowth (also termed secondary shoot regrowth potential), there were three times as many secondary shoots on intact controls after 2 months relative to the number present initially ($P \leqslant 0.0001$). This ratio was the same relative ratio as for root fresh weight (Table 1). Decapitating untreated plants decreased the number of secondary shoots that emerged

Table 1. Effect of site of clopyralid treatment and decapitation on Canada thistle regrowth.

Treatment		Emerged shoots at 2 months[ac]				Root fresh weight[abc]		Secondary shoots[abc]	
Clopyralid	Decapitation	Trial 1		Trial 2					
		(no.)	(%)	(no.)	(%)	(g)	(%)	(no.)	(%)
Control (at start)	—	—	—	—	—	32.5 cd	34	28 b	34
Control (after 2 months)	—	3.8 b	100	2.5 b	100	95.9 a	100	83 a	100
Foliar-treated	—	0.2 c	5	0.8 c	32	31.3 cd	33	3 d	4
Soil-treated	—	0.7 c	18	1.7 bc	68	81.1 b	85	12 c	14
Foliar- + soil-treated	—	0.3 c	8	1.3 bc	52	23.8 d	25	2 d	2
Control (after 2 months)	+	5.8 a	153	6.8 a	272	40.1 c	42	6 cd	7
Soil-treated	+	2.8 b	74	1.2 bc	48	20.6 d	22	1 d	1

[a]Means in a column followed by the same letter were not different by Duncan's multiple range test at P = 0.05.

[b]Data for two trials were combined.

[c]Replicates = 6 pots/treatment in each trial.

after 2 months relative to the start. Decapitating plants decreased the number of secondary shoots to the same extent as all clopyralid treatments 2 months after the start compared to the controls either initially or after 2 months. Secondary shoot regrowth ability was more severely reduced following shoot decapitation or clopyralid treatment than was root fresh weight. Soil-applied clopyralid did not decrease secondary shoot numbers of decapitated plants relative to decapitated controls after 2 months, even though root fresh weight was decreased.

The dry weights of secondary shoots were 10.3 and 0.9 g/pot for decapitated controls and decapitated clopyralid-treated plants, respectively, 5 weeks after harvest (P≤0.0001). Thus, growth of emerged secondary shoots was inhibited severely by soil-applied clopyralid even though the number of secondary shoots per plant was not reduced.

In contrast to my results with large Canada thistle, Hall et al. (12) concluded that foliar-applied clopyralid was less phytotoxic to small (8- to 10-leaf) Canada thistle than was foliar plus soil-applied clopyralid 42 days after treatment, as measured by emerged secondary shoot dry weight. Clopyralid was applied at 50 to 200 g/ha in their study, whereas 140 g/ha, the commercial rate of Curtail®, was applied in this study (Table 1). Hall et al. (12) removed the sprayed shoots 24 to 144 h after foliar treatment; plants were left intact for 2 months in this study (Table 1). Perhaps foliar treatment alone acts more slowly than foliar plus soil treatment to damage the roots and root buds; it may take longer for a phytotoxic concentration of clopyralid to accumulate in the roots following foliar application alone. Clopyralid uptake for only 144 h may not have been enough time to completely absorb the herbicide in the studies of Hall et al. (12). Alternatively, the relatively small plants used in their study may have responded differently to the herbicide than the older plants used in this research. Although no attempt was made to measure how much clopyralid reached the soil surface in the foliar plus soil treatment (Table 1), it is unlikely that very much herbicide reached the soil surface because of foliar interception of the spray. Perhaps the small

plants used by Hall et al. (12) intercepted less herbicide, permitting more herbicide to reach the soil for greater root uptake. The foliage of small plants also is likely to intercept quantitatively less herbicide than are larger plants. Finally, the parameters used to measure Canada thistle response to clopyralid were different in the two studies; Hall et al. (12) used secondary shoot dry weight whereas emerged shoot numbers, root fresh weight, and secondary regrowth potential of segmented roots were used to measure clopyralid damage in this study (Table 1).

Dose response. Soil surface-applied clopyralid prevented secondary shoot emergence after decapitating Canada thistle in either trial at doses ≥560 g/ha (Table 2).

Clopyralid did not kill all Canada thistle roots at any dose after 2 months although other differences were dramatic (Table 2). Roots were firm and white, at 11 to 140 g/ha clopyralid. Browning and severe loss of lateral roots occurred at rates ≥280 g/ha. At clopyralid rates ≥560 g/ha, roots were turgid, brown, and brittle and broke easily when they were removed from the soil although they were not necrotic.

The effects of soil-applied clopyralid on the regrowth potential of secondary shoots from root buds following root segmentation 2 months after clopyralid application are summarized in Table 2. The results of the two trials could not be combined, probably because high summer temperatures in the greenhouse severely reduced the secondary shoot regrowth potential in trial 2. For example, there were half as many secondary shoots in controls in trial 2 as in trial 1 (P≤0.0001) (Table 2). Secondary shoot emergence also was severely reduced midsummer in the field (16). In both trials, secondary shoot numbers were not reduced at 11 g/ha clopyralid. However, no secondary shoots emerged at rates >280 or >67 g/ha in trials 1 and 2, respectively.

Secondary shoot emergence of Canada thistle was reduced at lower clopyralid rates than was root fresh weight (Table 2). Roots were not killed 2 months after treatment at any dose that was tested. Perhaps new shoot emergence in soil is more sensitive to the herbicide than is root growth. When roots

Table 2. The effect of clopyralid rate on regrowth of decapitated Canada thistle 2 months after treatment.

Clopyralid rate	Emerged shoots[ab]				Root fresh weight[ab]				Secondary shoots[ab]			
	Trial 1		Trial 2		Trial 1		Trial 2		Trial 1		Trial 2	
(g/ha)	(no.)	(%)	(no.)	(%)	(g)	(%)	(g)	(%)	(no./plant)	(%)	(no./plant)	(%)
0	12.0 ± 2.2	100	13.0 ± 7.6	100	89.0 ± 20.0	100	68.4 ± 31.7	100	49.3 ± 28.2	100	26.3 ± 31.5	100
11	10.5 ± 3.3	88	10.5 ± 5.8	81	81.0 ± 15.2	91	83.5 ± 33.2	122	40.3 ± 10.5	82	27.0 ± 32.2	103
34	9.8 ± 5.2	82	13.8 ± 2.4	104	94.7 ± 44.5	106	65.2 ± 6.1	95	44.3 ± 34.7	89	5.3 ± 3.1	20
67	4.3 ± 5.0	36	9.5 ± 4.5	73	34.2 ± 30.2	38	57.2 ± 8.6	84	5.8 ± 7.2	12	0	0
140	2.3 ± 1.5	19	0.3 ± 0.5	2	22.3 ± 18.4	25	12.6 ± 8.3	18	0.5 ± 1.0	1	0	0
280	0.3 ± 0.5	3	0.8 ± 1.5	6	3.6 ± 0.6	4	14.1 ± 3.8	21	0	0	0	0
560	0	0	0	0	4.3 ± 1.8	5	19.1 ± 8.7	28	0	0	0	0
840	0	0	0	0	3.9 ± 1.7	4	8.4 ± 5.6	12	0	0	0	0
1120	0	0	0	0	4.6 ± 5.3	5	6.9 ± 2.2	10	0	0	0	0

[a]Means and standard deviations are presented.

[b]Replicates = 4 pots/treatment in each trial.

were unearthed, segmented to end correlative inhibition of adventitious root bud growth and placed in vermiculite, no secondary shoots grew following soil-applied clopyralid treatment at or above 280 and 67 g/ha in trials 1 and 2, respectively. Apparently, clopyralid did not reduce root fresh weight to the same relative extent as it reduced secondary shoot regrowth potential. The dose dependence of these growth parameters differed. Apparently, the number of secondary shoots was not reduced proportionately to decreases in root biomass.

Several studies documented the dose dependence of Canada thistle control in the field (24, 25, 32) and greenhouse (12) following foliar plus soil application of clopyralid or foliar treatment alone (12). Greatest parent shoot control and suppression of secondary shoot regrowth occurred at 100 and 200 g/ha clopyralid in these latter studies. This is the first report that clopyralid dose dependence may be similar for decapitated, soil-treated plants (Table 2) and foliar-treated plants (12, 24, 25, 32).

Clopyralid phytotoxicity to emerging shoots. Soil surface-applied clopyralid severely decreased the number of shoots emerging through treated soil (P≤0.0003 and 0.0001 in trials 1 and 2, respectively) (Table 3). One would expect that top-watering sprayed pots without a charcoal barrier would leach the herbicide into the emerging shoot and root zone. Apparently, both roots and/or emerging shoots must be exposed to clopyralid at 140 g/ha for it to inhibit emergence of new secondary shoots. Although shoot zone uptake of clopyralid was insufficient alone to reduce shoot emergence, it severely inhibited subsequent shoot growth, as measured by shoot dry weight (P≤0.0001) (Table 3). Emerged shoots were deformed, as well.

Shoot zone uptake of clopyralid was sufficient alone to reduce root biomass (P≤0.0001) (Table 3). When both emerging shoots and roots were exposed to clopyralid without a charcoal barrier, root fresh weight was much less than when only emerging shoots were exposed to the herbicide. Perhaps secondary shoots emerging through herbicide-treated soil were able to absorb and translocate enough herbicide to the roots to reduce root biomass. However, it is more likely that shoot zone uptake of clopyralid may have inhibited subsequent shoot growth and photoassimilation enough to limit later root growth over the 2 months of the experiment.

Secondary shoot regrowth potential was reduced to the same extent by either shoot zone or shoot plus root uptake of clopyralid (P≤0.0001) (Table 3). Secondary shoot regrowth was reduced equally by either type of clopyralid treatment, whereas root biomass of shoot zone-treated plants was 3.8-fold greater than shoot plus root zone-treated plants. As pointed out in the previous experiment, the extent to which clopyralid treatment reduced secondary shoot regrowth potential was not proportional to reduced root fresh weight. Critics may suggest that plant response to the shoot zone with clopyralid treatment was less than the shoot plus root zone treatment because the charcoal adsorbed the herbicide and less clopyralid was available for uptake by emerging shoots. While this criticism has merit, the extent to which adsorption influenced the observed response is problematic. Differences in secondary shoot regrowth potential and emerged shoot dry weight could not be distinguished between shoots plus root zone and shoot zone treatments (clopyralid plus charcoal layer) (Table 3), although differences were detected between these treatments for root fresh weight and emerged shoot number after 2 months.

This research is unique in that large, well-rooted Canada thistle plants were used, in contrast to most other greenhouse research (e.g., 12). Root system size is likely to influence the response of decapitated Canada thistle to soil-applied chlopyralid. Hall et al. (12) felt that the following factors modified the response of potted Canada thistle to post-emergence-applied clopyralid: soil organic matter, clay, and silt; soil moisture; the low soil to root volume of potted plants; and the distance between the roots and soil surface in pots. Soil-applied clopyralid controls Canada thistle more effectively in the greenhouse than in the field (12), but it may be because of the extensiveness and depth that roots of field-grown Canada thistle attain after several years of growth compared to the more limited root systems of potted plants. These greenhouse experiments complement field studies

Table 3. The effect of shoot versus shoot + root uptake of soil surface-applied clopyralid on Canada thistle growth, 2 months after potted plants were decapitated.

Treatment	Emerged shoots at 2 months[a][c]				Emerged shoot dry weight[a][c]				Root fresh weight[a][b][c]		Secondary shoots[a][b][c]	
	Trial 1		Trial 2		Trial 1		Trial 2					
	(no.)	(%)	(no.)	(%)	(g/plant)	(%)	(g/plant)	(%)	(g)	(%)	(g)	(%)
Control	6.1 a	100	12.0 a	100	3.0 a	100	1.5 a	100	57.2 a	100	30.4 a	100
Charcoal layer	6.5 a	107	12.4 a	103	2.3 a	75	1.5 a	100	55.1 a	96	24.8 a	82
Clopyralid	0.4 b	7	0.0 b	0	0.2 b	6	0	0	7.3 c	13	0.1 b	0.3
Clopyralid + charcoal	5.1 a	84	9.1 a	76	0.4 b	13	0.7 b	48	27.9 b	49	0.8 b	3

[a]Means in a column followed by the same letter were not different by Duncan's multiple range test at P = 0.05.

[b]Data for two trials were combined.

[c]Replicates = 8 pots/treatment in each trial.

by providing information on the response of individual plants to herbicides that would be difficult or impossible to gather in the field.

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