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Phytotoxic Effects, Regrowth, and ^{14}C-Sucrose Translocation in Canada Thistle Treated with Mefluidide, Flurprimidol, and Systemic Herbicides

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Abstract. Foliar applications of the plant growth regulators (PGRs) flurprimidol and mefluidide suppressed shoot elongation and regrowth and enhanced shoot injury caused by selected herbicides in Canada thistle (*Cirsium arvense* L.). Flurprimidol stimulated movement of ^{14}C-sucrose from leaves to roots. However, the stimulation was nullified when glyphosate, chlorsulfuron, or clopyralid was applied to foliage 1 week after application of the PGR. Herbicide-induced root injury was not enhanced by PGR application but these PGRs may be useful in decreasing weed competition among crops not similarly inhibited.

Deep-rooted perennial plants, such as Canada thistle, are significant weed problems, particularly where conservation tillage is practiced (Donald 1988). Canada thistle is not easily controlled because it has an extensive root system capable of supporting new shoot regrowth when the primary shoot is damaged or killed by herbicides (Peterson and Swisher 1985). Several herbicides can kill existing shoots and suppress regrowth but long-term control (i.e., root destruction) with one application of an herbicide generally has been unsuccessful (Hall et al. 1985). Glyphosate [*N*-(phosphonomethyl)glycine], clopyralid (3,6-dichloropicolinic acid), and chlorsulfuron [2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzensulfonamide] are phloem-mobile herbicides which translocate from foliage to roots and suppress regrowth but do not completely kill the Canada thistle root systems (Carlson and Donald 1988a, 1988b; Devine and Vanden Born 1985; Donald 1984, 1988; Hall et al. 1985; Turnbull and Stephenson 1985). Regrowth from Canada thistle roots was observed for most doses of clopyralid or chlorsulfuron by 42 days after herbicide treatment (Hall et al. 1985).

Plant growth regulators (PGRs) may be useful for management of perennial weeds like Canada thistle. Baradari et al. (1980) successfully used the PGR chlorflurenol (methyl-2-chloro-9-hydroxyfluorene-9-carboxylate) to enhance the movement of dicamba (3,6-dichloro-o-anisic acid) into roots of Canada thistle. Root meristems of below-ground tissues were stimulated by chlorflurenol, which increased basipetal translocation within the phloem. In other experiments, Baradari et al.'s method of stimulating root sinks was successful in controlled environments, but was less successful in the field (Tworkoski and Sterrett 1987).

An alternate tactic is to use PGRs to diminish above-ground growth with plant growth inhibitors, thereby altering sink demands and favoring herbicide movement to roots (Chykaliuk et al. 1982). Mefluidide [*N*-[2,4-dimethyl-5[[(trifluoromethyl)sulfonyl]amino]phenyl]acetamide] suppressed seed head development in annual bluegrass (*Poa annua* L.) resulting in accumulation of carbohydrates in the roots (Cooper et al. 1987, 1988). Similarly, Hanson and Branham (1987) demonstrated that movement of photosynthate to roots of 'Majestic' Kentucky bluegrass (*Poa pratensis* L.) could be enhanced following applications of mefluidide. Mefluidide applications to the perennial weed, leafy spurge (*Euphorbia esula* L.), increased picloram (4-amino-3,5,6-tricloropicolinic acid) transport from foliage to roots (Regimbal and Martin 1985).

Other PGRs, such as flurprimidol [a-(1-methylethyl)-a-[4-(trifluoromethoxy)phenyl]-5-pyrimidine methanol] and paclobutrazol [(2RS,3RS)-1-(4-chlorophenyl)-4,4,-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol], which inhibit shoot elongation, may also alter photoassimilate partitioning. Paclobutrazol and flurprimidol significantly reduced stem and new leaf weight but not root weight in 'Gala' apple (*Malus domestica* Borkh.) trees (Steffens 1988). Paclobutrazol decreased shoot weight in 12-week-old

'Red Delicious' apple seedlings, increased the root/shoot ratio, and increased photoassimilate transport to roots (El Hodairi et al. 1988). The change in assimilate distribution was attributed to decreased sink strength of the shoot apex.

The hypothetical basis for our experiments was that growth inhibitors, such as mefluidide and flurprimidol, may be able to inhibit shoot growth of Canada thistle. This could render it less competitive and also shift partitioning in the phloem toward the roots, which could increase herbicide movement to the roots. The primary objective of this research was to determine if shoot growth inhibitors reduce regrowth or improve control of Canada thistle by a systemic herbicide. The separate and combined effects of PGRs and of herbicides on plant injury, sucrose distribution (as an assessment of transport within the phloem), and on regrowth were determined.

Materials and Methods

Four experiments were conducted in the greenhouse and in a growth chamber. The first experiment established the effective rates of PGRs and their sites of absorption. The second experiment established the effective rates of herbicides. The third experiment elucidated the interaction between PGRs and herbicides and the fourth experiment was designed to investigate herbicide effects on PGR-stimulated sucrose transport.

Canada Thistle Growth Following PGR Application to Foliage Or to Soil

Six-week-old Canada thistle (approximately 10 cm tall with 8–10 leaves) that had been started from root cuttings were grown in 1-L pots under a 14-h photoperiod with supplemental light from metal-halide lamps (480 $\mu E\ m^{-2}\ s^{-1}$ PAR). Flurprimidol (50% a.i. wettable powder) was mixed with water containing Tween 20 (0.5% vt/vt used in all experiments) and applied to foliage with a laboratory sprayer (309 KPa) at a carrier volume of 533 L/ha at rates of 0.54, 0.27, or 0.05 kg a.i./ha. Soil was shielded from spray by a 2–3 cm layer of perlite which was removed by vacuum after the PGR dried. Water was applied to the soil surface as needed to avoid rinsing chemical from the shoot. Flurprimidol was mixed in aqueous Tween 20 at concentrations of 0.1 or 1.0 mg a.i./ml. One milliliter of either flurprimidol concentration was applied without foliar contact to the soil of pots containing Canada thistle.

Mefluidide (240 g a.i./L formulation) was mixed with water containing Tween 20 and applied to foliage, as described for flurprimidol, at rates of 5.4, 2.7, or 0.54 kg a.i./ha. Mefluidide was applied to soil of pots containing Canada thistle using the same technique and rates as used for flurprimidol.

Each treatment was applied to randomly selected plants and was replicated five times. Two weeks after PGR application, the height of the primary shoot was measured and shoots of plants in all treatments were removed. Final regrowth was measured 6 weeks after PGR application. The experiment was completely randomized and means are presented with standard errors.

Herbicide-Induced Injury and Regrowth of Canada Thistle

Canada thistle was grown from root cuttings for 5 months as described above but shoots were removed once to stimulate regrowth and provide an 8-week-old shoot, approximately 20 cm tall. Commercial formulations of herbicides were applied using the carrier rate and pressure described above. Glyphosate was applied at 4.48, 2.24, 1.12, 0.56, 0.28, 0.14, or 0.04 kg a.i./ha. Clopyralid was applied at 0.400, 0.300, 0.200, 0.100, 0.050, 0.025, 0.0125, or 0.0625 kg a.i./ha. Chlorsulfuron was applied at 0.200, 0.100, 0.050, 0.025, 0.013, 0.006, 0.003, or 0.002 kg a.i./ha. Treatments were replicated three times. Average shoot damage was evaluated visually 3 weeks after treatment by two people. Shoots were then removed. The number and height of regrowth shoots were measured weekly for 9 weeks. Roots then were visually evaluated for injury and dry weights measured. Experimental design and analysis were the same as the first experiment.

Regrowth, Injury, and ^{14}C-Sucrose Distribution Following Combined Applications of PGRs and Herbicides

Canada thistle plants were started from root cuttings. When the plants were 6-weeks old they received one of four possible PGR treatments using the foliar spray technique described in the first experiment. Soil was shielded during all treatments. The PGR treatments included 0.54 kg/ha mefluidide, 0.54 kg/ha flurprimidol, a mixture of mefluidide and flurprimidol to provide 0.54 kg/ha each, and aqueous 0.5% Tween 20 alone. Individual plants were treated 1 week later with a single rate of the commercial formulation of an individual herbicide as follows: glyphosate at 0.28, 0.56, or 1.12 kg a.i./ha; chlorsulfuron at 0.10, 0.20, or 0.40 kg a.i./ha; clopyralid at 0.10, 0.20, or 0.30 kg a.i./ha; and water as control.

Two weeks after herbicide treatment, shoot damage was estimated by two people and the shoots were excised. Regrowth of shoots was evaluated weekly until final harvest, 8 weeks after decapitation. Root damage was then evaluated. The experiment was designed as a factorial with four PGR treatments, four herbicide treatments, three rates per herbicide, and 10 replications per treatment combination for a total of 400 plants (experimental units). The effect of PGRs is presented for each herbicide rate as determined by Fisher's protected LSD with an experimental significance level of 0.10.

The effect of PGR and herbicide treatments on translocation was also evaluated. Canada thistle was grown and treated with PGRs as described previously. However, the herbicides were applied at a single rate: glyphosate at 0.56 kg a.i./ha, chlorsulfuron at 0.20 kg a.i./ha, or clopyralid at 0.20 kg a.i./ha. Three days after herbicide application, ^{14}C-sucrose (0.731 μCi in 20 μl/plant of a 100 mM sucrose solution in 0.5% Tween 20) was applied to a single donor leaf at the mid-stem position of the plant. Each herbicide/^{14}C-sucrose treatment was replicated three times. Canada thistle was kept under continuous light for 24 h until harvest. At harvest, the donor leaf was detached and nonabsorbed ^{14}C-sucrose was removed by rinsing with approximately 15 ml water and assayed for radioactivity. Shoots were detached from roots,

Table 1. Height of Canada thistle 2 weeks after PGR application and subsequent regrowth 6 weeks after PGR application.

PGR	Method of application	Rate	Height 2 weeks after application (cm)	Regrowth 6 weeks after application	
				Number	Height (cm)
Control		0	16.7 (0.7)[a]	6.3 (1.3)	4.3 (0.9)
Flurprimidol	Foliar	0.05 kg/ha	13.7 (1.2)	4.7 (0.3)	4.3 (0.9)
		0.27	10.3 (0.3)	2.3 (0.3)	1.7 (0.3)
		0.54	8.7 (1.5)	1.3 (0.7)	1.0 (0.6)
	Soil	0.1 mg/pot	10.7 (1.7)	3.0 (0.0)	1.0 (0.0)
		1.0	10.0 (1.9)	1.0 (1.0)	0.2 (0.2)
Mefluidide	Foliar	0.54 kg/ha	14.3 (2.4)	4.3 (0.3)	5.3 (0.9)
		2.70	12.0 (2.0)	3.7 (0.3)	8.7 (0.3)
		5.40	10.0 (1.0)	2.7 (0.9)	6.7 (0.3)
	Soil	0.1 mg/pot	16.0 (1.6)	3.7 (0.9)	7.7 (1.2)
		1.0	19.3 (0.9)	3.0 (0.0)	6.7 (1.2)

[a] Values in parentheses are the standard error of the means.

soil was washed from roots, and all plant parts were frozen with liquid nitrogen, lyophilized, and ground through a 10-mesh screen with a Wiley mill. Subsamples were then combusted, $^{14}CO_2$ captured and ^{14}C concentration in donor, shoot, and root were calculated (Peterson 1969). The distribution of ^{14}C was used as an indicator of the pattern of movement occurring within the phloem, as affected by the PGR and herbicide treatments. Means were separated as in the second experiment.

Distribution of ^{14}C-Sucrose and ^{14}C-Glyphosate Following Combined Applications of PGRs and Herbicides

Canada thistle plants were started from seed and each plant grown in a 1-L pot for 8 weeks in a growth chamber (16-h photoperiod; 156 μE m^{-2} s^{-1} PAR). Plants were treated foliarly with mefluidide or flurprimidol (0.54 kg/ha), grown an additional 7 weeks, and then half were treated with commercial formulation glyphosate (2.24 kg a.i./ha) with a laboratory sprayer. Glyphosate was applied prior to the end of PGR-induced shoot inhibition. After the glyphosate dried, ^{14}C-sucrose (0.2 μCi, as described above) was applied to half the glyphosate-treated and to half the no-glyphosate-treated plants. The remaining plants received ^{14}C-glyphosate (0.18 μCi, 52 mCi/mmol).

A single, healthy leaf located at midshoot received either ^{14}C-sucrose or ^{14}C-glyphosate. Prior to application, the ^{14}C-glyphosate was converted to the salt by adding 0.35 g isopropylamine/g acid. The ^{14}C-glyphosate was mixed with blank glyphosate surfactant (G-3780A, obtained from Monsanto, St. Louis, MO, USA) at a ratio of 0.5 g surfactant to 1.0 g acid. ^{14}C-Sucrose-treated plants were harvested 2 days after treatment and ^{14}C-glyphosate-treated plants were harvested 6 days after treatment. ^{14}C-Treated leaves were rinsed and the plant analyzed for ^{14}C distribution by dissecting plant tissue and combustion. Treatments were replicated five times.

Results and Discussion

Canada Thistle Growth Following PGR Application to Foliage Or to Soil

Most flurprimidol treatments suppressed height growth and regrowth (Table 1). Only the lowest foliar flurprimidol treatment did not inhibit regrowth. The highest rate of foliar-applied mefluidide inhibited height growth 2 weeks after application, but mefluidide also caused chlorosis and leaf malformation at the two higher rates. Hanson and Branham (1987) and Cooper et al. (1987, 1988) obtained seedhead suppression in *Poa* when mefluidide was applied at 0.28 kg/ha or less, and short-term yellowing of foliage occurred. We found that mefluidide applications of 0.54 kg/ha delayed flowering in Canada thistle for at least 3 weeks with no foliar chlorosis (data not shown). All flurprimidol soil treatments inhibited height growth of existing above-ground (primary) shoots and of regrowth. Soil-applied mefluidide suppressed the number and increased the height of regrowth shoots. It is possible that mefluidide translocated unevenly, inhibiting only some of the regrowth or that it inhibited regrowth at specific stages of development. Uninhibited regrowth may have grown taller due to greater resource availability.

Herbicide-Induced Injury and Regrowth of Canada Thistle

Canada thistle shoots were killed by glyphosate at 1.1 kg/ha, whereas the greatest injury to roots occurred at rates of 2.2 kg/ha or higher (Fig. 1a). Roots were not killed by glyphosate at 4.5 kg/ha, possibly due to rapid shoot death at higher rates which decreased glyphosate transport to the roots. The chlorsulfuron rates were more gradually related to phytotoxicity than glyphosate (Fig. 1b). Complete shoot kill was not attained with the highest chlorsulfuron rate used and root phytotoxicity rating was generally low.

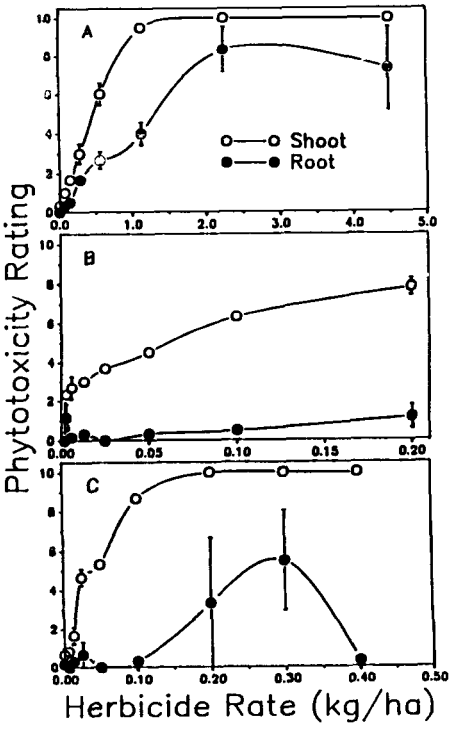

Fig. 1. Phytotoxicity ratings of shoot (open circles) and root (closed circles) resulting from applications of glyphosate (**A**), chlorsulfuron (**B**), or clopyralid (**C**). Phytotoxicity rating is the average of visual estimates of two people (0, no injury; 10, dead plant).

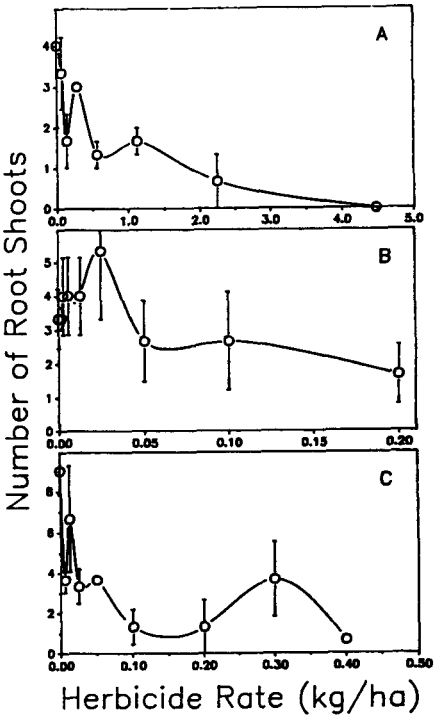

Fig. 2. Number of shoots that grew from Canada thistle roots 5 weeks after applications of glyphosate (**A**), chlorsulfuron (**B**), or clopyralid (**C**). Shoots were removed 2 weeks after herbicide application.

The effects of clopyralid rate followed the same general trend as those of glyphosate. Maximum shoot phytotoxicity occurred at clopyralid rates of 0.20 kg/ha and root phytotoxicity was considerably less for any given rate (Fig. 1c). Regrowth decreased with increasing herbicide rates (Fig. 2).

These results reinforce previous findings that shoot damage is a poor index of control of perennial weeds (Carlson and Donald 1988b). They also suggest that although regrowth may be suppressed (Fig. 2), the root is not necessarily killed (Fig. 1). We do not know how long Canada thistle roots will live without photosynthesizing shoots but they do remain viable at least 6 months under field conditions (Tworkoski, unpublished results).

It is likely that the differences in regrowth inhibition by the herbicides were due to differences in absorption, translocation, and modes of action. Glyphosate and chlorsulfuron translocate more slowly than clopyralid. Three weeks after treatment, 8% of the applied glyphosate was recovered from below-ground tissue in Canada thistle, and regrowth was reduced (Tworkoski and Sterrett 1987). Devine and Vanden Born (1985) reported that 5% of the applied chlorsulfuron had moved to roots by 6 days after treatment and 26% of the clopyralid by 1 day after treatment. They found that clopyralid markedly reduced regrowth but that chlorsulfuron did not. In the present experiment, clopyralid and chlorsulfuron inhibited regrowth similarly, although clopyralid was more inhibitory at lower rates. Clopyralid has an auxin-like mode of action. It may suppress regrowth by altering hormonal balance to favor suppression of adventitious shoot development. Glyphosate and chlorsulfuron inhibit amino acid synthesis and have less effect on regrowth.

Regrowth, Injury, and ^{14}C-Sucrose Distribution Following Combined Applications of PGRs and Herbicides

Analysis of variance revealed several interactions which precluded simplified combination of the data (Table 2). Nevertheless, general trends are apparent. Shoot injury was significantly affected by all main effects, including interactions. PGRs alone damaged thistle shoots but also enhanced herbicide toxicity to shoots (Table 2). Flurprimidol increased shoot injury resulting from all of the herbicide applications. Flurprimidol may have reduced herbicide detoxification. Cole and Owen (1987) and

Table 2. Injury and regrowth responses of Canada thistle following applications of selected PGRs and herbicides.

Herb[a]	Rate (kg/ha)	PGR	Injury[b]		Regrowth			
			Root	Shoot	Emergence (weeks)	Height (cm)	Dry wt (g)	Number
None	0	None	0.2	0.0	1.1	4.9	0.9	3.3
		F	0.0	1.2	1.4	3.0	1.0	3.7
		M	0.0	1.0	1.1	6.8	1.5	3.8
		F and M	0.1	1.7	2.6	2.1	0.6	3.1
		LSD (0.05)	0.1	0.3	1.3	1.8	0.4	NS
Gly	0.28	None	0.1	1.2	1.1	5.0	1.1	4.1
		F	0.1	2.2	1.8	2.7	0.7	5.1
		M	0.1	1.6	1.6	6.2	1.0	5.5
		F and M	0.2	3.0	2.0	2.1	0.7	1.9
		LSD (0.05)	NS	0.5	NS	1.4	NS	2.7
	0.56	None	0.6	2.1	2.0	4.9	0.8	4.6
		F	1.8	6.7	2.9	1.6	0.3	4.0
		M	0.9	1.8	2.5	4.0	0.5	6.9
		F and M	0.2	3.8	2.0	2.5	0.6	3.4
		LSD (0.05)	1.3	1.1	NS	1.2	0.3	2.4
	1.12	None	5.3	8.8	3.6	2.0	0.2	5.4
		F	3.9	9.5	3.5	1.2	0.2	6.5
		M	4.1	8.5	3.4	2.6	0.3	8.2
		F and M	2.1	6.2	3.5	2.0	0.3	3.4
		LSD (0.05)	NS	1.5	NS	NS	NS	3.7
Chlor	0.10	None	0.9	2.5	4.6	3.0	0.5	3.8
		F	0.2	5.6	3.6	1.6	0.4	5.3
		M	1.5	4.3	4.4	2.9	0.3	4.9
		F and M	0.0	5.4	3.9	1.7	0.5	2.6
		LSD (0.05)	NS	1.9	NS	NS	NS	NS
	0.20	None	3.9	3.7	6.9	1.0	0.1	1.5
		F	0.4	4.3	6.3	0.6	0.2	3.9
		M	1.5	4.0	5.7	1.7	0.2	4.1
		F and M	0.6	4.1	5.5	1.6	0.4	3.6
		LSD (0.05)	2.2	1.3	NS	NS	NS	2.0
	0.40	None	2.1	3.2	7.0	0.5	0.1	2.2
		F	2.7	5.7	6.2	0.6	0.1	4.9
		M	2.4	3.8	7.3	0.8	0.1	3.3
		F and M	0.8	5.2	4.7	0.7	0.2	3.1
		LSD (0.05)	NS	1.8	2.1	NS	0.1	NS
Clopyr	0.10	None	3.5	6.9	5.4	2.6	0.2	0.6
		F	6.0	8.5	4.5	1.6	0.1	0.7
		M	4.4	7.6	4.3	3.1	0.2	1.2
		F and M	2.8	7.2	4.3	2.0	0.3	1.2
		LSD (0.05)	NS	0.8	NS	NS	NS	NS
	0.20	None	4.2	8.3	5.6	2.4	0.2	0.7
		F	8.2	8.6	6.3	0.3	0.1	0.4
		M	5.6	8.1	6.6	1.3	0.1	0.3
		F and M	5.5	8.4	4.8	1.6	0.2	1.0
		LSD (0.05)	NS	0.8	NS	NS	NS	NS
	0.30	None	3.8	8.8	5.1	2.8	0.1	1.1
		F	6.3	9.6	4.0	0.8	0.1	1.0
		M	6.2	8.7	4.0	2.8	0.2	1.1
		F and M	7.1	8.3	6.8	0.5	0.1	0.2
		LSD (0.05)	NS	0.6	NS	NS	NS	NS
Main effects						(P > F)		
Herbicide			0.01	0.01	0.01	0.01	0.01	0.01
Rate			0.01	0.01	0.01	0.01	0.01	0.32
PGR			0.09	0.01	0.90	0.01	0.04	0.01
Herb × rate			0.01	0.01	0.06	0.12	0.01	0.04
Herb × PGR			0.03	0.01	0.24	0.01	0.01	0.01
Rate × PGR			0.99	0.01	0.91	0.34	0.37	0.55
Herb × rate × PGR			0.15	0.01	0.40	0.41	0.41	0.87

[a] Gly, glyphosate; Chlor, chlorsulfuron; Clopyr, clopyralid; F, flurprimidol; and M, mefluidide.
[b] Shoot damage was evaluated as the average of two visual estimates; 0, no injury and 10, dead plant.

Canivenc et al. (1989) decreased catabolism of chlortoluron (3-(3-chloro-*p*-tolyl-1,1-dimethylurea) in cell suspension cultures of *Triticum aestivum, Gossypium hirsutum,* and *Zea mays* with the PGRs tetcyclasis [5-(4-chlorophenyl)-3,4,5,9,10-pentoaza-tetra-cylo[5,4,1,$O^{2,6}$,$O^{8,11}$]dodeca-3,9-diene] and paclobutrazol. Flurprimidol has a mode of action similar to tetcyclasis and paclobutrazol and may inhibit degradation of chlorsulfuron.

The only significant interaction between PGRs and the herbicide rate resulted from combined applications of mefluidide and flurprimidol with glyphosate (Table 2). The combined PGRs caused greater shoot injury at low glyphosate rates and reduced injury at high rates compared to glyphosate alone. Consequently, the slope of the dose–response curve to glyphosate was significantly decreased when glyphosate applications were preceded by mefluidide and flurprimidol treatments (data not shown). Among the herbicides and rates applied, clopyralid caused the greatest shoot injury and chlorsulfuron caused the least (Table 2).

PGRs had little effect on root injury or on the time of regrowth emergence. Regrowth height was reduced by flurprimidol and by combinations of mefluidide and flurprimidol when applied alone or in combination with low rates of glyphosate. However, these PGRs did not consistently affect number or dry weight of regrowth shoots.

Clopyralid was most phytotoxic of the herbicides to roots and reduced regrowth effectively (Table 2). Glyphosate stimulated the number of regrowth shoots relative to control and increased their height compared with the other herbicides investigated. Chlorsulfuron was more phytotoxic to roots than was glyphosate but did delay regrowth as much as clopyralid. Regrowth shoots of controls emerged in 1 to 3 weeks, and in between 1 and 4 weeks from glyphosate-treated plants. On average, regrowth emergence from clopyralid of chlorsulfuron-treated plants was significantly later than from controls or glyphosate treatments, 5 to 6 weeks after decapitation. In general, increasing the rate of any herbicide increased root injury and inhibited the height but not the number of regrowth shoots. Low herbicide rates delayed regrowth by 1 to 2 weeks and medium and high rates delayed regrowth by 4 to 5 weeks.

^{14}C-Sucrose export from the donor leaf and movement into roots was greater in plants treated only with PGRs compared to untreated controls (Table 3). Herbicide applications in conjunction with PGRs diminished or reversed this effect. In particular, clopyralid-treated plants exported less sucrose from the donor leaf than did glyphosate or chlorsulfuron-treated plants. Clopyralid was faster-acting than the other herbicides based on the appearance of leaf damage within 1 week of treatment. The phytotoxicity of the herbicides masked the effect that PGRs alone had on sucrose transport to roots. Analysis of variance verified no interaction of PGR and herbicide on sucrose transport (data not shown). These results agree with earlier research (Tworkoski and Sterrett 1990), which demonstrated a slight but consistent increased movement of ^{14}C-sucrose into roots of Canada thistle treated with flurprimidol.

Table 3. Distribution of ^{14}C-sucrose in Canada thistle following applications of selected PGRs and herbicides.

PGR[a]	Herbicide	Distribution (%)		
		Shoot	Root	Donor
None	None	5.2	46.7	48.1
	Glyphosate	5.3	34.0	60.7
	Chlorsulfuron	5.2	56.5	38.3
	Clopyralid	6.1	21.5	72.4
F	None	5.8	60.8	33.4
	Glyphosate	2.9	38.9	58.2
	Chlorsulfuron	4.1	43.1	52.8
	Clopyralid	1.4	8.7	89.9
M	None	6.1	63.9	30.0
	Glyphosate	2.5	52.7	44.8
	Chlorsulfuron	3.8	44.1	52.1
	Clopyralid	2.4	11.5	86.1
F and M	None	6.5	62.3	31.2
	Glyphosate	7.7	50.1	42.2
	Chlorsulfuron	6.3	54.7	39.0
	Clopyralid	3.3	11.1	85.6
	LSD (0.05)	NS	21.5	22.5

[a] F, flurprimidol; M, mefluidide; F and M, combined PGR application of both flurprimidol and mefluidide.

Distribution of ^{14}C-Sucrose and ^{14}C-Glyphosate Following Combined Applications of PGRs and Herbicides

The distribution of ^{14}C-sucrose and ^{14}C-glyphosate within Canada thistle was the same; only the sucrose data are shown. The most salient PGR effect was the greater ^{14}C-sucrose accumulation in roots of Canada thistle following flurprimidol treatment (Table 4). Glyphosate decreased ^{14}C-sucrose partitioning into roots. These results coincide with the experiment discussed above and with Gougler and Geiger (1984), who suggested than an herbicide will alter partitioning and may limit its own translocation.

Although these results do not support the hypothesis that selected PGRs which inhibit shoot growth enhance movement of an herbicide to the roots of Canada thistle, ^{14}C-sucrose export from leaves and

Table 4. Distribution of the total radioactivity of foliarly applied ^{14}C-sucrose in Canada thistle following applications of PGRs and glyphosate.

		Distribution (%)		
Glyphosate[a]	PGR	Shoot apex	Shoot base	Root
Glyphosate not applied		24 a	8 b	68 a
Glyphosate applied		32 a	14 a	54 b
	No PGR	28 ab	14 a	58 b
	Mefluidide	39 a	11 ab	50 b
	Flurprimidol	18 b	7 b	75 a

[a] Within columns, means followed by the same letter do not differ at the 0.05 level based on Student Newman Keul's Test.

movement into roots was greatest in plants treated with either PGR versus subsequent herbicide treatment. While PGRs did not significantly increase the root injury by herbicides, flurprimidol did inhibit shoot regrowth height. This effect should be of value by decreasing weed competition in the field among crop species not similarly inhibited.

These experiments underscore the difficulty of controlling perennial weeds. Overall, glyphosate and clopyralid provided greater topkill than chlorsulfuron but clopyralid and chlorsulfuron inhibited regrowth the most. Flurprimidol inhibited regrowth height and mefluidide's greatest effect was the delay of flowering. Either of these growth regulation effects may be beneficial in a program to manage Canada thistle. Although flurprimidol slightly increased the ^{14}C content in roots, the stimulation was nullified when an herbicide was also applied. Therefore, it does not appear that flurprimidol or mefluidide will increase herbicide movement to roots of Canada thistle.

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