J Plant Growth Regul (1987) 6:221–232

Journal of
Plant
Growth
Regulation

Modification of Root Bud Growth in Canada Thistle with Selected Plant Growth Regulators: Effects on Translocation of Glyphosate

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Received June 17, 1987; accepted August 31, 1987

Abstract. Root applications of 0.1 μM 6-benzyladenine (BA) and 10.0 μM indole-3-butyric acid (IBA) enhanced or inhibited, respectively, root bud growth in hydroponically grown Canada thistle [*Cirsium arvense* (L.) Scop.]. Translocation of ^{14}C-glyphosate [*N*-(phosphonomethyl)glycine] into roots was positively correlated with this growth. Foliar applications of ethephon or chlorfluorenol also enhanced root bud growth, but glyphosate translocation was only weakly correlated with such growth in soil-grown Canada thistle. At glyphosate rates above 0.56 kg/ha, root bud growth was not stimulated by plant growth regulators (PGRs) and basipetal translocation was not enhanced. Paradoxically, ethephon and chlorflurenol restrained root bud growth in the field since thistle control steadily improved during the 3 years following treatment.

Canada thistle is a noxious weed that is widespread across North America (Hodgson 1968). Thistle root systems can expand horizontally to over 300 cm per year (Amor and Harris 1975), and independent plants can develop when adventitious buds and their aerial shoots grow from these roots (Moore 1975). Many root buds occur on a single thistle root, but most buds are suppressed by correlative factors (Hamdoun 1972) or environmental constraints. Root buds have been stimulated to produce shoots by temperature changes (Hoeffer 1981) as well as altered water and nitrogen availability (McIntyre 1979, McIntyre and Hunter 1975). Reduction of thistle populations is made difficult, since herbicides may not be translocated to the roots and root buds in lethal concentrations (Parker 1975). Some research has sought to stimulate root buds so that the resulting sink activity might promote basipetal translocation of a foliar-applied herbicide (Baradari et al. 1980, McIntyre and Hunter 1975, Hoefer 1981).

Some plant growth regulators (PGRs) have been reported to stimulate bud activity in several weed species, possibly by interfering with a correlative signal (Baradari et al. 1980, Chykaliuk et al. 1982, Tworkoski and Sterrett 1984, Waldecker and Wyse 1985). Several of these investigations have revealed much variability in response to PGR treatments, particularly in the field. The current research was designed to evaluate more closely the relationship between PGR treatment, herbicide movement, and root bud activity in Canada thistle.

The objectives were to (1) identify PGRs that stimulate development of root buds in Canada thistle, (2) determine the effect of root bud number and growth on basipetal translocation of a foliar-applied systemic herbicide, and (3) determine whether a root bud-enhancing PGR can improve efficacy of a systemic herbicide applied to Canada thistle.

Materials and Methods

Root Bud Stimulation by PGRs

Canada thistle was germinated and grown in soil (2:1:1:1, loam:peat:sand:vermiculite, v/v/v/v) for ~5 weeks to the rosette stage before treatment. In one experiment, soil was thoroughly rinsed from roots, and each plant was placed in a 1-liter container of aerated, half-strength Hoagland's solution at 25 ± 1°C with a 12-h photoperiod and 158 μE m^{-2} s^{-1} PAR. One week after plant transfer, solutions of benzyladenine (BA), indolebutyric acid (IBA), abscisic acid (ABA), ethephon [(2-chloroethyl)phosphonic acid], or gibberellic acid (GA_3) were added to the hydroponic medium at final concentrations of 10.0, 1.0, or 0.1 μM. Four weeks after PGR treatment, root bud number and total root bud length were measured.

A second PGR experiment was conducted with 5-week-old Canada thistle plants growing in 1-liter containers of the soil medium, but otherwise under the same environmental conditions. The foliage of each plant was sprayed to the point of runoff with flurprimidol [α-(1-methylethyl)-α-(4-trifluoromethoxy)-phenyl-5-pyrimidine methanol], chlorflurenol (methyl 2-chloro-9-hydroxyfluorene-9-carboxylate:methyl 9-hydroxyfluorene-9-carboxylate:methyl 2,7-dichloro-9-hydroxyfluorene-9-carboxylate, 8.8/2.1/1.6, v/v/v), ethephon, GAF 141 [(2-chloroethyl)phosphonic acid + *N*-methylpyrrolidone], atrinal [sodium salt of 2,3:4,6 bis-*O*-(1-methylethylidene)-*O*-L-xylo-2-hexulofuranosonic acid], or BA at concentrations of 100, 10, 1, 0.1, or 0.01 mM.

Treatments were replicated 5 times, and means were separated by Duncan's new multiple range test.

Glyphosate Translocation Response to Root Bud Growth

Canada thistle was grown from seed and prepared as described in the previous hydroponic experiment. One week following transfer, each nutrient solution was modified by adding 0.1 μM BA, 10.0 μM IBA, or no PGR treatment.

Glyphosate (isopropyl amine salt formulation) was applied concurrently with the PGRs or sequentially 1 week following BA or IBA. Droplets containing a total of 1200 μg glyphosate were applied to leaves of each plant. Two leaves per plant (donor leaves) received droplets of ^{14}C-glyphosate [*N*-(phosphono-^{14}C-methyl)glycine; 1.97 mCi/mM]. Plants treated concurrently received 0.8 μCi/plant and those treated sequentially received 0.6 μCi/plant. All plants were harvested 2 weeks after BA or IBA was added to roots. A randomized complete block design with 5 replications was used.

At harvest, plants from 4 replications were each dissected into 4 shoot and 4 root segments. All plant parts were lyophilized and weighed. Number and length of buds from each root segment were also measured. Subsamples of each dried plant part were then assayed for radioactivity by combustion (Peterson 1969), followed by liquid scintillation spectrometry. Since previous studies have demonstrated little metabolism of glyphosate (Gottrup et al. 1976), we assumed that the ^{14}C activity was closely correlated with ^{14}C-glyphosate. Means were separated by Waller-Duncan k-ratio *t* test. Relationships between herbicide translocation and root bud number, length, and weight were investigated by correlation analysis and by multiple linear regression. One plant from each treatment was autoradiogrammed (Crafts and Yamaguchi 1964).

Glyphosate Translocation Following Foliar Applications of Ethephon

Canada thistle was grown from seed for 10 weeks in 1-liter containers of soil at 25 ± 3°C with a 14-h photoperiod and 350 μE m^{-2} s^{-1} PAR. At treatment, all plants were ~30 cm tall at the flower bud stage. A 3 × 6 factorial experiment was conducted with ethephon as one main effect (0, 10, and 100 mM concentrations) and glyphosate as the other (0, 0.56, 1.12, 1.68, 2.24, and 3.36 kg/ha). Each of the 18 treatment combinations was applied as an over-the-top spray (10 plants/treatment). Three of the 10 plants in each treatment also received ^{14}C-glyphosate by treating two adjacent leaves (donor leaves) near the midpoint of a stem with 0.1 μCi ^{14}C-glyphosate. Four weeks after treatment, plants were harvested and the following variables measured: root and shoot weights, area of living leaves, number and weight of root buds that had emerged (root shoots) or had not emerged from the soil surface (root buds) (terminology of McIntyre and Hunter 1975), and root and shoot injury, based on the average of three visual estimates. Radioisotope distribution was evaluated by detaching donor leaves and rinsing them with 40 ml of a directed stream of methanol (unabsorbed glyphosate) and by separating apical shoot (above donor leaves), basal shoot (below donor leaves), and roots. Plant parts were quantified for radioactivity as described previously.

In a parallel experiment, similarly treated plants were used to quantify glyphosate accumulation in roots with time and to correlate glyphosate accumulation with root bud growth. Plants were grown as above and treated with 10 mM ethephon and 1.68kg/ha glyphosate. Ten replications each were harvested 1, 2, 3, 4, and 5 weeks after treatment. Three of the 10 replications for each harvest interval initially received ^{14}C-glyphosate. In both experiments, main effects

were tested using orthogonal contrasts (Ostle and Mensing 1975). Where appropriate, effects were examined for linear and quadratic relationships.

Response to PGRs and Glyphosate in the Field

Based on our greenhouse results and previously reported data (Peterson 1983, Baradari et al. 1980, Beasley 1969), chlorflurenol and ethephon were selected as potential stimulators of root buds in the field. Glyphosate (4.5 kg/ha) was applied alone, tank mixed with 1 mM ethephon or with 0.1 mM chlorflurenol, or applied sequentially 1 week after the two PGRs. Spray applications were made in June 1984 (561 l/ha) to 2-m^2 plots. Prevalent weeds were foxtail [*Setaria glauca* (L.) Beauv.], bindweed (*Convolvulus arvensis* L.), and velvetleaf (*Abutilon theophrasti* Medic). During the growing seasons of 1984, 1985, and 1986, the number of thistle stems and percent area covered by thistle (visual estimate of two people) were measured. The experimental design was a randomized complete block with 8 treatments and 4 replications. Means were separated by Waller-Duncan k-ratio *t* test.

Results and Discussion

Root Bud Stimulation by PGRs

In our controlled environment experiments, foliar applications of chlorflurenol, and ethephon and root applications of BA, stimulated development of root buds. Untreated hydroponically grown thistle produced 7 root buds with a total length of 346 cm (Table 1). Stimulation of root bud formation occurred only in BA-treated plants (Table 1). The 0.1-μM BA-treated plants produced 16 buds with a total length of 1164 cm. In contrast, IBA (at 1 and 10 μM) suppressed growth (30 cm). These results suggest that a cytokinin/auxin balance, which is thought to regulate the correlative inhibition of buds in shoots (Phillips 1975), may also be regulating shoots that arise adventitiously from roots. Other investigators have also reported that bud growth is stimulated by direct cytokinin application to subterranean parts of milkweed (*Asclepias syriaca* L.) (Waldecker and Wyse 1985) and Johnsongrass (*Sorghum halpense*) (Beasley 1969).

Among the foliar-applied PGRs, 0.1 mM chlorflurenol caused the greatest and most consistent stimulation of root bud growth (20 buds, 104 cm long) compared to control (12 buds, 53 cm long) (data not shown). Of the two ethylene-releasing PGRs, 1 mM ethephon caused greater root bud growth (15 buds, 85 cm long). Based on these and other data (Baradari et al. 1980, Beasley 1969), chlorflurenol and ethephon were used to stimulate root bud growth in subsequent experiments.

Herbicide Translocation and Root Bud Growth of Hydroponically Grown Thistle

Basipetal movement of foliar-applied glyphosate was correlated with PGR-promoted increases in root bud growth. If BA was applied before glyphosate, it

Table 1. Root bud growth of Canada thistle resulting from plant growth regulator applications to hydroponic media.

PGR type	PGR concentration (μM)	No. of buds	Total bud growth (cm)
Control		7 a[a]	346 bc
BA	10	10 ab	72 ab
	1	16 b	311 bc
	0.1	16 b	1164 d
IBA	10	3 a	30 a
	1	4 a	39 a
	0.1	6 a	241 bc
ABA	10	7 a	176 bc
	1	5 a	316 bc
	0.1	6 a	516 c
Ethephon	10	7 a	376 bc
	1	7 a	434 bc
	0.1	5 a	382 bc
GA_3	10	10 ab	818 c
	1	6 a	490 bc
	0.1	6 a	588 c

[a] Within each column, means followed by the same letter do not differ at the 0.05 level.

produced significantly more root bud growth than other PGR treatments (Table 2). This growth was concentrated in the 10-cm section immediately below the root collar (Fig. 1). More glyphosate moved to below-ground parts in this treatment than in any other (70% compared to 51% or less). Waldecker and Wyse (1985) were able to stimulate root bud accumulation of lethal quantities of glyphosate in milkweed root buds by applications of BA. Increased root bud activity in Canada thistle also enhanced basipetal movement of dicamba (Baradari et al. 1980) and glyphosate (Hoefer 1981). Our BA treatment enhanced movement of subsequently applied glyphosate, but not to lethal concentrations.

Glyphosate movement was more closely associated with sink strength than with sink number. For example, glyphosate content in roots was more strongly correlated with average root bud length ($r = 0.71$) than with number of buds ($r = 0.15$) (Table 3). Although glyphosate content decreased with increasing distance from the root collar (Table 2), glyphosate concentration remained uniform along the root (~20,000 dpm/g). The sink activity within 10 cm of the root collar did not suppress glyphosate distribution to root apices. Autoradiograms illustrate a rather uniform ^{14}C-glyphosate distribution in roots (Fig. 1).

Bud growth and basipetal translocation were stimulated when roots were treated hydroponically with BA prior to herbicides (Table 2). Shaw et al. (1983) also found that pretreating a root bud-producing weed with a PGR (GAF 141) stimulated basipetal movement of glyphosate whereas near-simultaneous treatment inhibited it. In contrast, Baradari et al. (1980) reported greater dicamba movement to Canada thistle roots when it was applied simultaneously with chlorflurenol. Our results with hydroponic studies demonstrate that root bud stimulation by root applications of selected PGRs can be counteracted by

Table 2. Growth and ^{14}C distribution in Canada thistle in a growth chamber following hydroponic root applications of BA or IBA and concurrent or subsequent foliar treatments of ^{14}C-glyphosate.

Time of PGR and glyphosate application	PGR treatment	Root dry wt[a] (g)	Shoot dry wt[b] (g)	Bud no.	Bud length (cm)	Distribution of translocated ^{14}C-herbicide (%)							
						Below ground	Root section[c] 1		2		3		4	
							Root	Bud	Root	Bud	Root	Bud	Root	Bud
Concurrent	BA	0.3 c	0.5 c	7 bc	7 bc	31 b	20	3	7	—[d]	1	—	—	—
	IBA	0.4 bc	0.5 c	3 c	3 c	51 b	23	5	19	—	4	—	—	—
	Control	0.6 a–c	0.8 c	6 bc	5 c	36 b	18	2	11	—	4	—	1	—
Sequential	BA	1.0 a–c	1.3 bc	12 a	47 a	70 a	13	31	10	4	6	—	6	—
	IBA	1.1 ab	2.0 ab	5 bc	20 bc	43 b	11	16	9	1	4	—	2	—
	Control	1.3 a	2.3 a	8 ab	25 b	44 b	10	9	7	4	3	—	11	—

[a] Means within a column that are followed by the same letter are not significantly different at the 0.05 level.
[b] Excluding donor leaves.
[c] Root section 1 = 0–10 cm from root collar, 2 = 10–20 cm, 3 = 20–30 cm, and 4 = 30 cm to root apex.
[d] (–) Designates no buds present on root section.

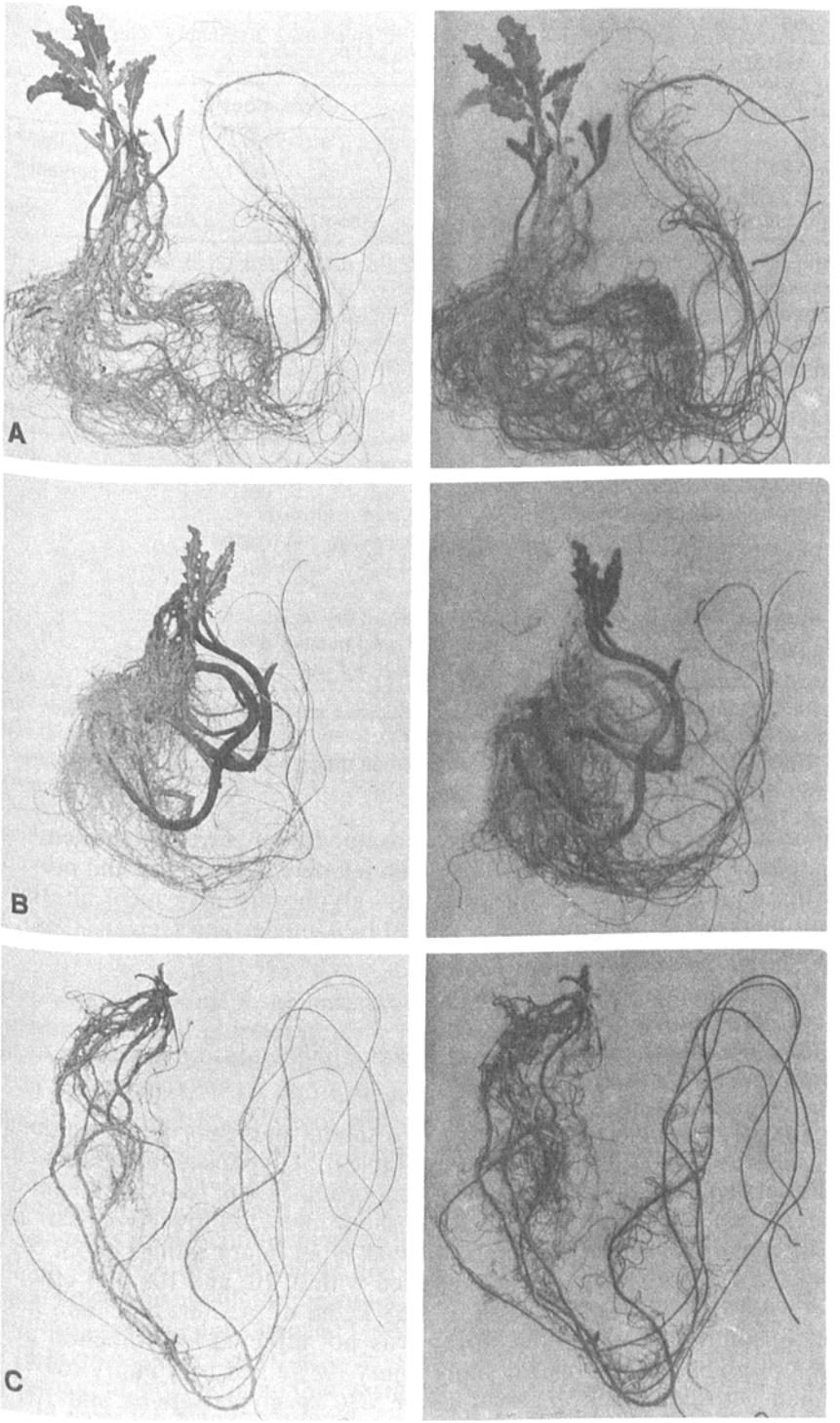

Fig. 1. ^{14}C distribution in roots and root shoots of Canada thistle treated with ^{14}C-glyphosate and (A) BA, (B) IBA, or (C) water alone. Plants are on left and autoradiographs are on right.

Table 3. Correlations and regression equations of ^{14}C-glyphosate distribution with components of thistle growth.

	Correlations[a]			
	Hydroponically grown ^{14}C content		Soil grown ^{14}C content	
Growth component	Root	Shoot	Root	Shoot
Root weight	0.53*	0.45*	0.74*	0.28*
Shoot weight	0.45*	0.72*	0.36*	0.31*
Total no. buds	0.15	−0.15	0.28	−0.09
Total length buds	0.52*	−0.14	NM	NM
Total weight buds	0.64*	−0.05	0.28	−0.13
Average bud length	0.71*	0.04	NM	NM
Average bud weight	0.70*	0.15	0.12	−0.01

Regression equations[b]

^{14}C content (% of applied) in roots of hydroponically grown thistle $= 1.02 + 2.16$ root dry weight $+ 0.89$ average bud length $[r^2 = 0.63\ p > f = 0.01]$

^{14}C content (% of applied) in roots of soil-grown thistle $= 0.18 + 0.76$ root dry weight $+ 0.05$ total number of buds $[r^2 = 0.58\ p > f = 0.01]$

[a] Pearson correlation coefficients; *designates significance at the 0.05 level. NM indicates variable not measured.

[b] Best-fit multiple linear regression equations based on the stepwise procedure.

simultaneous foliar application of glyphosate. In concurrent treatments, glyphosate may have moved to areas of potential meristem activity and prevented BA stimulation of growth. Alternatively, glyphosate may have altered the carbon metabolism of leaves, as reported by Gougler and Geiger (1984), and disrupted phloem transport.

Glyphosate Translocation Following Foliar Applications of Ethephon to Canada Thistle Growing in Soil

Four weeks following treatment, injury to shoots and roots increased quadratically with increasing glyphosate rates (Table 4). Glyphosate effects reached a maximum of 1.68 kg/ha (91% injury of shoots and 56% of roots). Ethephon had an interactive effect with glyphosate on shoot injury: at low glyphosate rates, ethephon markedly increased injury (visual shoot injury ratings of 53, 65, and 81% when 0.56 kg glyphosate was applied with 0, 10, and 100 mM ethephon, respectively); at glyphosate rates of 1.68 kg/ha or greater, ethephon had no effect on injury ratings. Root injury was not affected by ethephon at any dosage of glyphosate. Greatest shoot injury (98%) and root injury (69%) was obtained with combined applications of 3.36 kg glyphosate/ha and 100 mM ethephon.

Table 4. Injury of soil-grown Canada thistle and root bud and root shoot growth 4 weeks after glyphosate and ethephon applications in the greenhouse.

Glyphosate (kg/ha)	Ethephon (mM)	Shoot injury[a] (%)	Root injury (%)	Root shoot		Root bud	
				No.	Wt (g)	No.	Wt (g)
0	0	9	1	3	3.1	2	0.08
	10	28	6	3	2.6	3	0.09
	100	40	7	8	4.5	4	0.10
0.56	0	53	18	3	0.8	6	0.13
	10	65	17	3	0.9	9	0.09
	100	81	23	3	1.3	10	0.15
1.12	0	79	33	2	1.5	6	0.09
	10	83	47	2	0.7	7	0.09
	100	88	43	1	0.5	6	0.12
1.68	0	91	56	2	1.2	5	0.07
	10	90	59	2	0.9	6	0.09
	100	90	57	2	1.2	5	0.09
2.24	0	87	54	2	0.8	7	0.10
	10	89	39	2	1.0	7	0.10
	100	89	53	2	1.3	9	0.13
3.36	0	94	59	2	0.7	5	0.07
	10	91	45	2	1.6	4	0.08
	100	98	69	2	0.6	3	0.08
LSD (0.05)		12	19	1.6	0.9	4.5	0.06
Effects ($p > f$)							
Ethephon (E)		0.01[b]	0.23	0.07	0.07	0.58	0.23
Linear ethephon		0.01	0.10	0.02	0.07	0.31	0.24
Glyphosate (G)		0.01	0.01	0.01	0.01	0.01	0.01
Quadratic glyphosate		0.01	0.01	0.01	0.01	0.01	0.05
E × G		0.01	0.50	0.01	0.06	0.87	0.90

[a] Injury ratings of 0 indicate no damage and 100 represents a dead plant.
[b] Any probability value greater than 0 but less than 0.005 was rounded to 0.01.

Glyphosate movement, as measured by ^{14}C activity, was linearly related to application rates of glyphosate, but not ethephon (data not shown). ^{14}C-glyphosate concentration was high following applications of 1.68 kg/ha compared to 0.56 kg/ha (4093, 4058, and 6782 dpm/g compared to 2001, 2249, and 3356 dpm/g in the shoot apex, shoot base, and root, respectively). ^{14}C content in roots of these soil-grown thistles was not significantly correlated with root bud number or dry weight (Table 3). In general, root bud growth had less effect on ^{14}C movement in soil-grown than in hydroponically grown thistle.

Glyphosate translocation apparently occurs for a limited time following application. Growth of root shoots and root buds increased with time (Table 5), but glyphosate accumulation in roots did not increase. After 1 week, ^{14}C concentrations remained unchanged (~4000 dpm each week). Most foliar absorption of glyphosate occurred by 3 days after application in Canada thistle, and Sandberg et al. (1980) found that basipetal translocation may continue between 3 and 14 days following treatment. Our work indicates that little translocation

Table 5. Growth and injury of soil-grown Canada thistle and distribution of ^{14}C-glyphosate during 5 weeks following foliar treatments with ethephon (10 mM) and glyphosate (1.68 kg/ha) in the greenhouse.

Plant part	Variable[a]	Weeks following treatment 1	2	3	4	5	Trend[b]
Shoot	Dry weight (g)	5.0	6.3	5.1	4.0	5.2	NS
	Leaf area (cm^2)	439	334	55	28	0	LIN
	Donor dpm	78,200	112,000	111,000	107,000	91,000	NS
	Shoot dpm	65,800	15,700	9,840	5,280	16,500	NS
	Injury (%)	60	70	90	90	90	LIN
Root	Dry weight (g)	0.52	0.78	0.89	0.70	1.44	LIN
	dpm	5,680	4,720	3,590	3,420	3,670	NS
	Injury (%)	10	40	40	60	40	QUAD
Root shoot	Number	1.4	2.3	2.6	2.1	2.4	NS
	Dry weight (g)	0.36	0.93	1.24	0.86	1.84	LIN
	dpm	2,300	1,360	3,600	495	1,110	NS
Root bud	Number	1.2	1.3	5.2	5.6	8.9	LIN
	Dry weight (g)	0.01	0.03	0.09	0.09	0.13	QUAD
	dpm	380	—	3,380	412	519	NS

[a] Growth and injury measurements are based on 10 replications harvested each week. ^{14}C content (dpm) is derived from 3 of those replications. Injury values of 0 indicate no damage and 100 indicate a dead plant.

[b] Orthogonal contrasts were used to determine nonsignificant (NS) or significant linear (LIN) and quadratic (QUAD) changes in measured variables with time. Contrasts were considered significant at the 0.05 level.

occurred after 7 days following treatment. It is possible that at rates of 1.68 kg/ha and above, shoots were too badly injured to support transport. Hunter and Smith (1972) found delayed topkill of Canada thistle may provide better control, due to greater translocation to roots. However, results from our study indicate that lower glyphosate doses did not kill roots satisfactorily. Although basipetal translocation can be enhanced when low glyphosate rates are used, such rates will likely be too low to control thistle effectively. Five weeks after treatment, thistle treated with ethephon (10 mM) and glyphosate (1.68 kg/ha) appeared to be recovering by means of vigorous root buds/shoots.

Thistle Response to Glyphosate and PGRs in the Field

Neither sequentially applied nor tank-mixed PGRs consistently improved thistle control by glyphosate in the field. During 1984, only ethephon enhanced the effects of glyphosate in reducing weed density (from 28 to 17 plant m^{-2})

Table 6. Number of thistle plants per square meter and percent ground area covered by thistle after applications of glyphosate and/or PGRs in 1984.

Treatment[a]	1984		1985		1986	
	No.	Area (%)	No.	Area (%)	No.	Area (%)
Alone Water	28 ab[b]	21 cd	43 a	38 a	56 a	33 ab
E	24 bc	23 bc	26 bc	20 de	16 e	13 d
C	33 a	26 a–c	19 c	19 e	12 e	11 d
G	28 ab	27 a–c	31 b	26 bc	45 bc	27 bc
Sequential E/G	23 bc	23 bc	27 b	23 c–e	54 ab	38 a
C/G	28 ab	28 ab	27 b	25 cd	31 d	23 c
Concurrent E + G	17 c	16 d	30 b	26 bc	52 a–c	27 bc
C + G	33 a	29 a	30 b	31 b	44 c	23 c

[a] The following symbols were used: E = ethephon, C = chlorflurenol, and G = glyphosate. Applications of PGRs and glyphosate were separate (alone), 1 week apart (sequential), or tank mixed together (concurrent).
[b] Means within each column followed by the same letter do not differ at the 0.05 level.

and area covered (from 27 to 16%). In 1985, percent thistle coverage decreased in response to all PGR or herbicide treatments, compared to control (Table 6). However, during 1986, PGRs reduced glyphosate's effects on thistle number and coverage. These results underscore the variability of plant responses to PGRs. As in investigations by others (Peterson 1983, Shaw et al. 1983), we found PGRs could stimulate root bud activity and enhance basipetal herbicide translocation under laboratory or greenhouse conditions, but, in the field, enhanced control was not obtained. It seems likely that environmental variation, as well as herbicide counteraction of PGR-induced root bud activity, was responsible for lack of PGR effects.

By the third posttreatment growing season, the number of thistles in the field was reduced most by chlorflurenol or ethephon. Besides stimulating root bud outgrowth, both of these PGRs may have inhibited subsequent elongation. Ethephon reduces internode elongation (Abeles 1973), and chlorflurenol inhibits development of growing tips (Weed Science Society of America 1983). Following their initial stimulatory effect on bud outgrowth, both PGRs, or a metabolite, may have slowly accumulated in root meristems to inhibitory levels, and eventually reduced topgrowth.

Based on our investigation, PGR promotion of root bud development (perhaps by release from correlative inhibition) is possible, although it may be a transient phenomenon with a new dominance hierarchy developing. Although basipetal transport of foliar-applied glyphosate is positively correlated with root bud growth, the impact of the activity on glyphosate transport is less in soil-grown than in hydroponically grown thistle. These factors, together with the uncertainty of timing for a foliar herbicide application to take advantage of unseen root meristem activity, present a formidable task for enhancing herbicide translocation with PGRs. A direct tactic for reducing competition from weeds that reproduce adventitiously from roots may entail suppressing growth and development of root shoots. In our field experiment, we obtained

the greatest long-term thistle control by applications of either chlorflurenol or ethephon.

References

Abeles FB (1973) Ethylene in plant biology. Academic Press, New York, 302 pp

Amor RL, Harris RV (1975) Seedling establishment and vegetative spread of *Cirsium arvense* (L.) Scop. in Victoria, Australia. Weed Res 15:407–411

Baradari MR, Haderlie LC, Wilson RG (1980) Chlorflurenol effects on absorption and translocation of dicamba in Canada thistle (*Cirsium arvense*). Weed Sci 28:197–200

Beasley CA (1969) The effect of various chemicals on axillary bud development in Johnsongrass rhizomes. Proc Weed Sci Soc Am no. 190, Las Vegas, NV

Chykaliuk PB, Peeper TF, Basler E (1982) Stimulation of basipetal herbicide translocation with GAF 141. Weed Sci 30:6–10

Crafts AS, Yamaguchi S (1964) The autoradiography of plant materials. Calif Agric Exp Stn Ext Serv Manual 35, 143 pp

Gottrup O, O'Sullivan PA, Schraa RJ, Vanden Born WH (1976) Uptake, translocation, metabolism and selectivity of glyphosate in Canada thistle and leafy spurge. Weed Res 16:197–201

Gougler JA, Geiger DR (1984) Carbon partitioning and herbicide transport in glyphosate-treated sugarbeet (*Beta vulgaris*). Weed Sci 32:546–551

Hamdoun AM (1972) Regenerative capacity of root fragments of *Cirsium arvense*. Weed Res 12:128–136

Hodgson JM (1968) The nature, ecology and control of Canada thistle. US Dep Agric Tech Bull 1382, 32 pp

Hoeffer RH (1981) Canada thistle (*Cirsium arvense*) root bud initiation, biology, and translocation of ^{14}C-glyphosate as influenced by nitrogen, temperature, photoperiod, and growth stage. PhD dissertation, University of Nebraska, Lincoln, NE, 82 pp

Hunter JH, Smith LW (1972) Environment and herbicide effects in Canada thistle ecotypes. Weed Sci 20:163–167

McIntyre GI (1979) Developmental studies on *Euphorbia esula*. Evidence of competition for water as a factor in the mechanism of root bud inhibition. Can J Bot 57:2572–2581

McIntyre GI, Hunter JH (1975) Some effects of the nitrogen supply on the growth and development of *Cirsium arvense*. Can J Bot 53:3012–3021

Moore RJ (1975) The biology of Canadian weeds. Can J Plant Sci 55:1033–1048

Ostle B, Mensing RW (1975) Statistics in research. Iowa State University Press, Ames, IA, 596 pp

Parker C (1975) Effects on the dormancy of plant organs. In: Audus JJ (ed) Physiology–biochemistry, ecology, Vol 1. Academic Press, London, pp 168–187

Peterson JI (1969) A carbon dioxide collection accessory for the rapid combustion apparatus for preparation of biological samples for liquid scintillation analysis. Anal Biochem 31:189–201

Peterson PJ (1983) Absorption, translocation, and metabolism of chlorsulfuron and the effects of herbicide–growth regulator combinations on Canada thistle (*Cirsium arvense*) control. PhD dissertation, University of Nebraska, Lincoln, NE, 75 pp

Phillips IDJ (1975) Apical dominance. Annu Rev Plant Physiol 26:341–367

Sandberg CL, Meggitt WF, Penner D (1980) Absorption, translocation and metabolism of ^{14}C-glyphosate in several weed species. Weed Res 20:195–200

Shaw DR, Peeper TF, Basler E (1983) The influence of herbicide concentration on stimulation of basipetal herbicide translocation by GAF 141. Proc 36th South Weed Sci Soc Am, p 387

Tworkoski TJ, Sterrett JP (1984) Translocation of triclopyr and glyphosate in Canada thistle after root treatments of 6-benzyladenine and indole-3-butyric acid. Proc 11th Plant Growth Regul Soc, p 208

Waldecker MA, Wyse DL (1985) Chemical and physical effects of the accumulation of glyphosate in common milkweed (*Asclepias syriaca*) root buds. Weed Sci 33:605–611

Weed Science Society of America (1983) Herbicide handbook, 5th edn. Weed Science Society of America, Champaign, IL, 515 pp