Relationship of Leaf Position to Herbicide Absorption and Organosilicone Adjuvant Efficacy[1]

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Abstract. The absorption of ^{14}C-bentazon and ^{14}C-acifluorfen by individual leaves of velvetleaf was measured from the cotyledons to the most recently developed leaf in plants that had developed seven leaves beyond the cotyledons. Herbicide absorption 1 min after application was greatly enhanced by the organosilicone adjuvant Sylgard 309 explaining previously observed enhanced efficacy and rainfastness by this adjuvant. ^{14}C-herbicide absorption was greatest by the cotyledons and decreased upward to the most recently developed leaf. Absorption of the ^{14}C-Sylgard 309 was similar to that of the ^{14}C-labelled herbicides and was not related to the number of stomata or leaf area covered by the spray droplets. These results are consistent with the hypothesis that the mode of action of Sylgard 309 is to enhance cuticular absorption and not stomatal infiltration. **Nomenclature:** Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; bentazon, 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide; velvetleaf, *Abutilon theophrasti* Medicus #[4] ABUTH.

Additional index words: Acifluorfen, bentazon, crop oil concentrate, growth stage, Sylgard 309, ABUTH.

INTRODUCTION

Optimum weed control with POST herbicides generally requires application of the herbicide before the weeds reach a given height or stage of growth (5, 6, 13). Attempts have been made to relate leaf age, maturity, and position on the plant to various cuticular and epicuticular characteristics and all of these to herbicide absorption. Kirkwood et al. (8) reported that absorption of MCPA [(4-chloro-2-methylphenoxy)acetic acid] and MCPB 14-(4-chloro-2-methylphenoxy)butanoic acid] absorption was greater by younger leaves than older leaves in *Vicia faba* L. Similar results have been reported by Sargent and Blackman (17) with 2,4-D [(2,4-dichlorophenoxy)acetic acid] and by King and Radosevich (7) with triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}. Increased triclopyr absorption by immature tanoak [*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.] was attributed to less cuticular wax and more permeable cuticular membranes in the immature leaves than in the mature leaves (7).

After studying nine plant species, Norris (11) concluded that 2,4-D penetration was not related to cuticle thickness and that qualitative differences in the cuticle were of greater importance. Davis (3) observed that individual wax crystals were two to three times larger on the surface of first-formed pea (*Pisum sativum* L.) leaves than on sixth-formed leaves. In contrast to the report of Norris (11), Pereira et al. (12) related the tolerance of certain cabbage (*Brassica oleracea* var. *capitata* L.) cultivars to nitrofen [2,4-dichloro-1-(4-nitrophenoxy)benzene] to decreased deposition of cuticular waxes. In a recent study Bergman et al. (1) distinguished clear differences between leaves near the base of the alfalfa (*Medicago sativa* L.) plants and those nearer the shoot apex. Leaves near the base of the plant had less total epicuticular wax, triacontanol, and wax esters per unit leaf area and had more triacontanol on their surfaces than leaves nearer the shoot apex. The most likely explanations for the empirical observation of greater POST herbicide efficacy on young plants of limited height compared with older, larger plants are greater herbicide absorption or less herbicide metabolism by the younger plants.

The organosilicone adjuvant, Sylgard 309[5] was observed by Roggenbuck et al. (16) to greatly increase the efficacy and rainfastness of Na-bentazon and Na-acifluorfen on velvetleaf plants 7.5 to 12.5 cm tall. Velvetleaf

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[4]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds. Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

[5]Sylgard 309 silicone surfactant is an organosilicone adjuvant mixture containing the active ingredient 2-(3-hydroxypropyl)-heptamethyltrisiloxane, ethoxylated, and acetate manufactured and marketed by Dow Corning Corp., Midland, MI 48686-0994.

absorbed maximum levels of both the ^{14}C-Sylgard 309 and ^{14}C-labelled herbicides bentazon and acifluorfen within 15 min following application (15). Organosilicone adjuvants greatly reduce surface tension of the spray solution (16). Field and Bishop (4) and Buick et al. (2) propose that the organosilicone adjuvants act by increasing stomatal infiltration of the spray solution. The results obtained by Roggenbuck et al. (16) indicate that reduction of surface tension and the efficacy of organosilicones for increasing herbicide efficacy did not appear to be related, and thus do not support the mode of adjuvant action proposed by Field and Bishop (4) and Buick et al. (2).

The objective of this study was to determine the relationship between leaf position in velvetleaf and the absorption of bentazon and acifluorfen as influenced by adjuvants and how this relates to the basis of Sylgard 309 action.

MATERIALS AND METHODS

Velvetleaf was planted in greenhouse potting soil in 945-ml pots. After emergence, the velvetleaf was thinned to one plant per pot. The plants were grown in the greenhouse at 25 ± 2 C and received supplemental lighting from sodium vapor lamps to provide a daytime maximum of 1200 $\mu E/m^2/s^1$ for both supplemental and natural lighting. The plants were maintained at an 18-h day/6-h night regime and watered as needed.

For the radioisotope studies, the ^{14}C-acifluorfen (667 kBq/μ mol uniform phenoxy ring-labelled) and the ^{14}C-bentazon (384 kBq/μ mol uniformly benzene ring-labelled) were mixed with water, the respective formulated product, and the adjuvants to simulate a field application rate of 0.15 kg/ha Na-acifluorfen or 0.63 kg/ha of Na-bentazon delivered in 234 L/ha spray volume. When the velvetleaf had seven leaves beyond the cotyledons, the ^{14}C-bentazon was applied alone or with 1% crop oil concentrate[6] or with 0.375% Sylgard 309 as a 2-μl drop containing 0.37 kBq to the adaxial surface of a single leaf per plant. Applications to cotyledons through the leaf in position number 7 as diagrammed in Figure 1 were made to separate plants. The ^{14}C-acifluorfen was applied in a similar manner at an acifluorfen rate of 0.15 kg/ha alone, with X-77[7] surfactant, or with Sylgard 309 at 0.375%. The

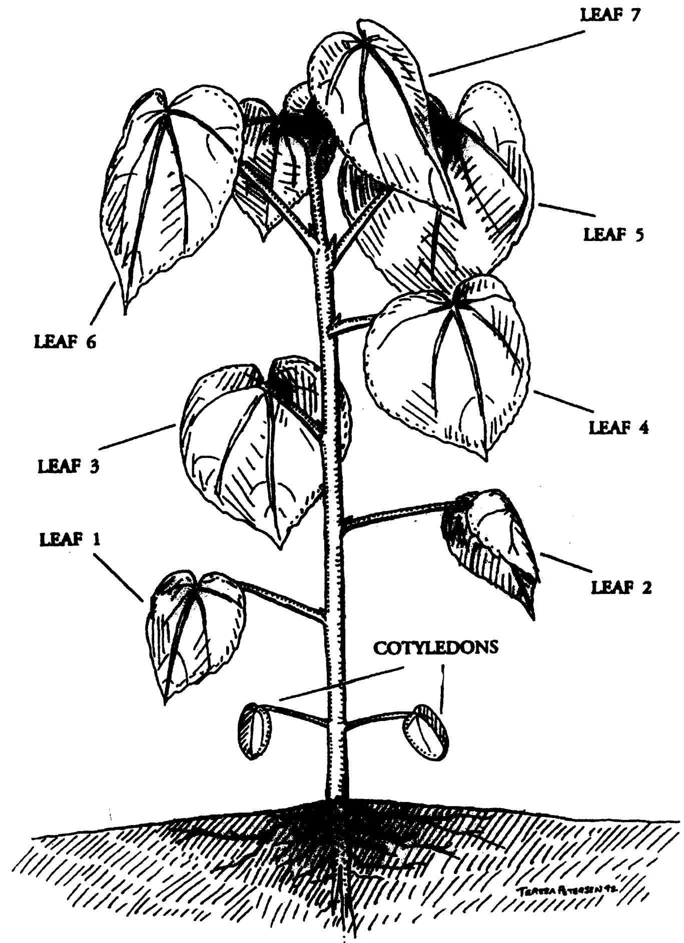

Figure 1. Diagrammatic scheme of a velvetleaf plant indicating the numbering of the leaves used for reporting absorption data.

^{14}C-Sylgard 309 (477 kBq/g) was mixed with water and applied alone or with a herbicide to simulate a field application rate of 0.375% adjuvant in 234 L/ha spray volume. The Sylgard 309 solution was applied as five 2-μl drops containing a total of 0.222 kBq. The ^{14}C-labelled materials were washed off the leaf surface after 1 min with a 45-s rinse of 1:1 methanol:water for ^{14}C-acifluorfen and ^{14}C-Sylgard 309 or a 1:1 ethanol:water for the ^{14}C-bentazon. The amount of ^{14}C not removed by the rinse was considered absorbed.

The number of stomata per unit leaf area was determined by painting 5% cellulose acetate in acetone on the leaf surface with a brush. After drying the acetate film was peeled off the leaf and examined under a binocular microscope.

The data reported are the means of two experiments with

[6]Herbimax, a crop oil concentrate containing 83% petroleum oil and 17% surfactant, is marketed by Loveland Industries, Inc., Greeley, CO 80632.

[7]X-77 nonionic surfactant is a mixture of alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol marketed by Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596.

Table 1. Effect of adjuvants on ^{14}C-bentazon absorption by velvetleaf leaves relative to leaf position.

Leaf position	Absorption in 1 min[a] Na-bentazon alone	Na-bentazon + COC[b]	Na-bentazon + Sylgard 309
	% of applied		
Cotyledon	0.6	0.4	85.9
Leaf 1	0.2	0.5	72.1
Leaf 2	0.4	0.5	74.9
Leaf 3	0.3	0.1	54.8
Leaf 4	0.1	0.2	25.1
Leaf 5	0.2	0.6	13.3
Leaf 6	0.1	0.0	3.0
Leaf 7	0.9	0.5	1.3
LSD (0.05)		6.8	

[a]Sylgard 309 concentration was 0.375%, COC concentration was 1%, and Na-bentazon rate was 0.63 kg/ha.

[b]COC = crop oil concentrate (Herbimax).

Table 2. Effect of adjuvants on ^{14}C-acifluorfen absorption by velvetleaf leaves relative to leaf position.

Leaf position	Absorption in 1 min[a] Na-acifluorfen alone	Na-acifluorfen + X-77	Na-acifluorfen + Sylgard 309
	% of applied		
Cotyledon	1.6	0.5	86.4
Leaf 1	2.3	0.2	80.4
Leaf 2	1.6	1.1	76.9
Leaf 3	1.0	0.4	55.3
Leaf 4	1.3	0.1	42.5
Leaf 5	3.7	4.8	48.1
Leaf 6	9.2	5.7	14.7
Leaf 7	5.3	6.9	8.5
LSD (0.05)		7.8	

[a]Sylgard 309 and X-77 concentrations were 0.375%, Na-acifluorfen rate was 0.15 kg/ha.

four replications each. A factorial design was used for the analysis of variance.

RESULTS AND DISCUSSION

Na-bentazon absorption in 1 min by velvetleaf was negligible if applied alone or with crop oil concentrate (Table 1). Na-bentazon absorption by the cotyledons was over 85% of that applied in 1 min when Sylgard 309 was present in the spray solution. The percentage of ^{14}C-bentazon absorbed decreased with leaf position up the plant, with the youngest leaves absorbing the least (Table 1). The rate and pattern of ^{14}C-acifluorfen absorption were very similar to that observed with ^{14}C-bentazon (Table 2). The rapid herbicide absorption in the presence of the Sylgard 309 is consistent with the enhanced rainfastness previously observed with this adjuvant (16). The pattern of absorption with the leaves of the plant nearest the crown or base of the plant absorbing more than the leaves near the shoot apex is consistent with the common observation that POST herbicides are more effective on younger plants (5, 6, 13). It is also consistent with the observation of McWhorter et al. (10) that the weight of wax per unit of surface area in johnsongrass (*Sorghum halepense* (L.) Pers.) is greater for the younger leaves than for the older leaves near the crown. McWhorter (9) suggests that young cells may be more efficient in wax production than older cells or if wax production occurs at a steady rate, continued cell expansion dilutes the wax on the leaf surface on a weight per unit surface area basis.

The ^{14}C-Sylgard 309 absorption was also very rapid and approximated that of ^{14}C-bentazon and ^{14}C-acifluorfen with respect to the percent absorbed by the cotyledons and subsequent leaves above the cotyledons (Table 3). The presence of Na-bentazon or Na-acifluorfen in the spray solution appeared to retard slightly ^{14}C-Sylgard 309 absorption. This would be expected if adjuvant micelles containing herbicides were formed. The similarities in absorption of the adjuvant Sylgard 309 and the Na-bentazon and Na-acifluorfen may be indicative of the adjuvant acting as a co-penetrant. Riederer and Schönherr (14) speculated that adjuvants that enhance herbicide absorption most likely have to enter the cuticle to affect the

Table 3. ^{14}C-Sylgard 309 absorption by velvetleaf leaves relative to leaf position.

Leaf position	Absorption in 1 min[a] Sylgard 309 alone	Sylgard 309 + Na-acifluorfen	Sylgard 309 + Na-bentazon
	% of applied		
Cotyledon	87.7	79.0	53.1
Leaf 1	74.7	59.5	20.8
Leaf 2	65.2	53.5	10.8
Leaf 3	58.1	36.4	12.8
Leaf 4	36.4	14.3	13.0
Leaf 5	28.0	6.2	9.9
Leaf 6	10.2	5.3	7.2
Leaf 7	5.9	5.8	6.6
LSD (0.05)		12.3	

[a]Sylgard 309 concentration was 0.375%, Na-acifluorfen rate was 0.15 kg/ha, and Na-bentazon rate was 0.63 kg/ha.

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Table 4. Velvetleaf adaxial leaf surfaces and Sylgard 309: effect of Sylgard 309 on ^{14}C-acifluorfen absorption, droplet spread, stomate density, and stomata contacted per droplet.

Leaf position	^{14}C-acifluorfen absorption	Spread of 2-µl droplet	Stomate density	Stomata contacted
	% in 1 min	cm^2	no. per mm^2	no. per droplet
Cotyledon	86	0.95	63	5985
Leaf 1	80	1.92	90	17280
Leaf 2	77	2.86	109	31174
Leaf 3	55	3.88	131	50828
Leaf 4	43	4.16	125	52000
Leaf 5	48	4.15	156	64740
Leaf 6	15	4.98	134	66732
Leaf 7	9	5.34	172	91848
LSD (0.05)	7.8	0.73	44	

permeability of the cuticle to water and its solutes. This differs sharply from the hypothesis of Field and Bishop (4) that organosilicone adjuvants exert their efficacy by reducing surface tension and greatly enhancing stomatal entry of the herbicide. If stomatal entry played a role in the action of organosilicone adjuvants one would expect a direct relationship between herbicide absorption and the number of stomata covered by a droplet of the spray solution. The data in Table 4 indicate that the number of stomata and leaf area covered by a droplet of spray solution containing Sylgard 309 has no relationship to the efficacy of the adjuvant. The data support the conclusion that penetration of the adjuvant into the cuticle is important and that the action of Sylgard 309, and likely other organosilicone adjuvants, does not depend on stomatal infiltration for efficacy.

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