MIXING HERBICIDES ALTERS THEIR BEHAVIOR IN WOODY PLANTS

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ABSTRACT. Additive effects were observed in absorption and lateral and downward movement of 2,4,5-T ester and dicamba applied singly and in combination to woody plants of four species. Mixing paraquat with either or both of the other herbicides reduced the uptake of paraquat and, with a single exception, reduced or had no effect on the activity of other active components of the mixtures.

Two or more herbicides are frequently mixed to kill resistant species (1, 2). Brady (3) found that a mixture of 2 pounds of 2,4,5-T and 2 pounds dicamba ae per acre was more effective for late-summer treatment of a stand of mixed brush in central Louisiana than 4 pounds of either herbicide alone. Reported here are effects of applying three herbicides singly and in combinations.

A plant is killed by a herbicide when it translocates a lethal amount to its roots or growing regions (6). In the present study, absorption and lateral and downward translocation were measured in four species of woody plants.

Methods and Materials

The species chosen, sweetgum (*Liquidambar styraciflua* L.), water oak (*Quercus nigra* L.), red maple (*Acer rubrum* L.), and loblolly pine (*Pinus taeda* L.), are common in forests of central Louisiana. Sweetgum is classed as susceptible, water oak as intermediate in resistance, and red maple as resistant to foliar sprays. Two-year-old greenhouse-grown plants were tested. They ranged from 16 to 48 inches tall, but plants of a uniform size were selected within each species.

Formulations tested consisted of three herbicides (2,4,5-T ester, dicamba, and paraquat)[1/] alone and in all two- and three-chemical mixtures. All were water solutions containing 2 percent (by weight) of active ingredients. Since the mixtures contained equal quantities of each herbicide with a concentration totaling 2 percent, half as much of each component was present in the two-chemical mixture as in single-chemical formulations. Similarly, a three-chemical mixture reduced an individual herbicide concentration to one-third. This procedure had both advantages and disadvantages. It made direct comparisons of absorption and translocation among one-, two-, and three-chemical mixtures difficult.

1/ The 2,4,5-T ester for the experiment was supplied by the Thompson Hayward Chemical Company; the paraquat by the Ortho Division of the Chevron Chemical Company; the dicamba and C^{14}-labeled dicamba by the Velsicol Chemical Corporation.

On the other hand, the concentrations of individual chemicals are usually reduced in formulations for field use. Also, applying a constant total phytotoxin concentration eliminated the possibility of high concentrations causing undue damage to absorbing and translocating structures of treated plants. To each dicamba solution enough C^{14}-labeled herbicide was added to provide 1.5 / 10^{-2} μc of radioactivity.

One-half ml. of one of the herbicide formulations was applied to the foliage on one side of each plant. On the treated side several drops of herbicide were applied to each leaf with a hypodermic syringe. Each combination of chemicals was applied to four plants of each species.

Ninety-six hours after the solutions were applied, samples were taken from treated and untreated foliage, and roots of each plant. They were washed and taken to the laboratory for analyses.

Each sample was extracted with suitable solvents and the extracts analyzed for the herbicides applied to the plant. Paraquat was detected by the colorimetric procedure of the Chevron Chemical Company,[2/] 2,4,5-T by gas-liquid chromatography, and dicamba by liquid-scintillation counting of the C^{14} activity. Values are expressed in μg of active herbicide per gram of dry weight of plant tissue. Herbicides recovered from the untreated foliage were taken as a measure of lateral translocation, those from the roots as basipetal movement, and the combined amounts from the three samples as total absorption.

Results and Discussion

In most instances, absorption and translocation of individual herbicides were not significantly reduced by applying them in mixtures, even though the rate of application was only 50 and 33 percent as great in the two- and three-herbicide combinations as in the single-herbicide formulations. In some instances, an expression of probable effectiveness for an individual herbicide was increased by mixing.

Compared with values obtained in studies at other seasons (3, 4), absorption and translocation of all three herbicides applied in September in the present study were low. These low values are a reflection of the well-known late-season resistance of most woody species to herbicides. Absorption of 2,4,5-T by hardwoods was not decreased by mixing with dicamba (table 1). Basipetal and total movement in water oak was higher from the mixture with dicamba than from 2,4,5-T alone. No such increase occurred in sweetgum and red maple.

Paraquat in the formulation reduced 2,4,5-T absorption by sweetgum, but not by either of the other hardwood species. Translocation of 2,4,5-T was not influenced in any of the hardwoods by the presence of paraquat.

2/ Chevron Chemical Company. Analysis of paraquat residues--method RM-8. File No. 740.10. Richmond, California. January 30, 1967.

Less 2,4,5-T was absorbed by red maple from the three-chemical mixture than from the single-herbicide formulation, but this reduction did not occur in the other two hardwood species. Basipetal movement was lower in sweetgum but higher in water oak from the three-chemical mixture than from the formulation containing only 2,4,5-T. Higher total translocation in water oak is the result of greater basipetal movement.

The effects of mixing herbicides on the behavior of 2,4,5-T in loblolly pine were mixed. Absorption was reduced in the presence of paraquat. Basipetal and total translocation were increased with dicamba present, while total translocation was decreased by the presence of paraquat.

Dicamba has been less effective than 2,4,5-T in most late-season spray programs, and our data may show why. In sweetgum, absorption of dicamba was about two-thirds as great as absorption of 2,4,5-T (tables 1 and 2). Translocation of dicamba in all three hardwood species ranged from less than one-third to about two-thirds that of 2,4,5-T. Low translocation of dicamba in woody species is somewhat surprising since Magalhaes et al. (5) had reported that dicamba was freely mobile in nutsedge and that it could, under certain conditions, move out of the treated plants into the surrounding soil. By contrast, 2,4,5-T is usually considered to move only in a source-to-sink direction in treated plants.

Absorption of dicamba by water oak and red maple was lower from mixtures containing 2,4,5-T than from the one-chemical solution, but lateral and total movement in water oak was higher from the mixture.

Paraquat also reduced the uptake of dicamba by water oak and red maple but had no significant effect on its translocation. Dicamba absorption was lower by water oak from the three-chemical mixture but movement was not affected in any of the hardwoods.

The only effect of mixing herbicides on the behavior of dicamba in loblolly pine was a decrease in absorption from the three-chemical mixture.

In each comparison, the combined absorption and translocation of 2,4,5-T plus dicamba was greater from the two-chemical mixtures than it was for either single herbicide from a one-chemical solution, even though the total phytotoxin concentration was the same in both solutions. The mixture of these two herbicides is commonly found to be more effective against woody species than either applied alone, especially for late-season treatments. This increase may be the result of the combined activity of the two components.

Absorption of paraquat was lower from all mixtures containing it than from the single-chemical formulation (table 3). In red maple and loblolly pine, paraquat could not be detected in foliage treated with mixtures.

Movement of paraquat in treated woody plants could not be measured if it occurred. This result was not totally unexpected since paraquat is primarily a desiccant and contact herbicide. The treated foliage had browned in the 96 hours between treatment and harvest of samples. There were no visual

Table 1.--Absorption and translocation of 2,4,5-T from four formulations[1/]

Chemical formulation	Total absorbed	Lateral translocation	Basipetal translocation	Total translocation
	----------	----------	μg/g	----------
			Sweetgum	
2,4,5-T only	363	97	85	182
2,4,5-T plus dicamba	346	86	76	162
2,4,5-T plus paraquat	269 (S)	90	71	161
Three-chemical mixture	334	111	59 (S)	170
			Water oak	
2,4,5-T only	150	39	37	76
2,4,5-T plus dicamba	169	45	66 (S)	111 (S)
2,4,5-T plus paraquat	144	35	46	81
Three-chemical mixture	187	46	64 (S)	110 (S)
			Red maple	
2,4,5-T only	142	38	36	74
2,4,5-T plus dicamba	130	35	35	70
2,4,5-T plus paraquat	137	43	38	81
Three-chemical mixture	100 (S)	33	32	65
			Loblolly pine	
2,4,5-T only	225	57	46	103
2,4,5-T plus dicamba	280	59	82 (S)	131 (S)
2,4,5-T plus paraquat	146 (S)	39	29	68 (S)
Three-chemical mixture	190	47	44	91

1/ Values for mixtures followed by (S) differ significantly at the 5-percent level from those for 2,4,5-T only, according to Dunnett's test for individual comparisons.

Table 2.--Absorption and translocation of dicamba from four formulations[1/]

Chemical formulation	Total absorbed	Lateral translocation	Basipetal translocation	Total translocation
	µg/g			
			Sweetgum	
Dicamba only	149	31	23	54
Dicamba plus 2,4,5-T	143	31	24	55
Dicamba plus paraquat	198	26	27	53
Three-chemical mixture	205	20	49	69
			Water oak	
Dicamba only	237	23	33	56
Dicamba plus 2,4,5-T	161 (S)	63 (S)	28	91 (S)
Dicamba plus paraquat	182 (S)	23	23	46
Three-chemical mixture	96 (S)	19	30	49
			Red maple	
Dicamba only	192	27	19	46
Dicamba plus 2,4,5-T	85 (S)	20	19	39
Dicamba plus paraquat	82 (S)	25	20	45
Three-chemical mixture	163	33	20	53
			Loblolly pine	
Dicamba only	179	47	32	79
Dicamba plus 2,4,5-T	200	38	32	70
Dicamba plus paraquat	148	47	30	77
Three-chemical mixture	102 (S)	34	29	63

1/ Values for mixtures followed by an (S) differ significantly at the 5-percent level from those for dicamba only, according to Dunnett's test for individual comparisons.

Table 3.--Absorption of paraquat from four formulations by four woody species[1/]

Chemical formulation	Sweetgum	Water oak	Red maple	Loblolly pine
	---------------------	µg/g	---------------------	
Paraquat only	369	207	38	250
Paraquat plus 2,4,5-T	165 (S)	73 (S)	0	0
Paraquat plus dicamba	171 (S)	51 (S)	0	0
Three-chemical mixture	97 (S)	71 (S)	0	0

1/ Values followed by an (S) differ significantly at the 5-percent level from those for paraquat only, according to Dunnett's test for individual comparisons.

symptoms on untreated foliage. These data indicate no advantage for two-chemical mixtures of paraquat and either of the other herbicides or for three-chemical mixtures in which paraquat is one of the components.

Additive effects of mixtures were evaluated by combining absorption and translocation values for all components to derive a single value for each formulation on each species (table 4). These values are a poor measure of the relative effectiveness of the several formulations on the different species because each species responds differently from every other to each of the three phytotoxins included in the formulations. They may, however, provide a valid comparison of the absorption and translocation of total phytotoxin by an individual species.

Low absorption and translocation of all three herbicides from these early September treatments demonstrate a cause for poor success from late-season spraying. Comparatively few differences were noted in absorption of 2,4,5-T or dicamba. Greater variations in uptake were expected, because the concentration of each herbicide in the applied spray ranged from 0.67 percent to 2 percent active ingredients. The small variations indicate that plant response to late-season treatments is likely to be limited by physiology of the plant rather than by chemical exposure.

Table 4.--Total absorption and translocation of all herbicides from seven formulations

Chemical formulation	Total absorbed	Lateral translocation	Basipetal translocation	Total translocation
	----------	----------	μg/g	----------
			Sweetgum	
2,4,5-T only	363	97	85	182
Dicamba only	149	31	23	54
Paraquat only	369	...	...	...
2,4,5-T plus dicamba	489	117	100	217
2,4,5-T plus paraquat	434	90	71	161
Dicamba plus paraquat	353	26	27	53
Three-chemical mixture	636	131	108	239
			Water oak	
2,4,5-T only	150	39	37	76
Dicamba only	237	23	33	56
Paraquat only	207	...	...	...
2,4,5-T plus dicamba	330	108	94	202
2,4,5-T plus paraquat	217	35	46	81
Dicamba plus paraquat	233	23	23	46
Three-chemical mixture	354	65	94	159
			Red maple	
2,4,5-T only	142	38	36	74
Dicamba only	192	27	19	46
Paraquat only	38	...	...	...
2,4,5-T plus dicamba	215	55	54	109
2,4,5-T plus paraquat	137	43	38	81
Dicamba plus paraquat	82	25	20	45
Three-chemical mixture	263	66	52	118
			Loblolly pine	
2,4,5-T only	225	57	46	103
Dicamba only	179	47	32	79
Paraquat only	250	...	...	...
2,4,5-T plus dicamba	480	97	114	201
2,4,5-T plus paraquat	146	39	29	68
Dicamba plus paraquat	148	47	30	77
Three-chemical mixture	292	81	73	154

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