659.
Publication 19

Reprinted from *WEEDS*
Vol. 16, No. 3, July 1968

Herbicide Combinations for Woody Plant Control[1]

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Abstract. We studied 4-amino-3,5,6-trichloropicolinic acid (picloram) alone and in combination with 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) or 1,1'-dimethyl-4,4'-bipyridinium salt (paraquat) for control of several greenhouse, nursery, and natural-grown, woody plant species. Picloram:paraquat combinations improved the control of some species such as yaupon (*Ilex vomitoria* Ait.) as compared to picloram alone at equal rates; but it had an antagonistic effect on huisache (*Acacia farnesiana* (L.) Willd.) and honey mesquite (*Prosopis juliflora* (Swartz) DC. var. *glandulosa* (Torr.) Cockerell). Evaluation of picloram: 2,4,5-T combinations suggested that 2,4,5-T sometimes could be added in equal amounts to picloram to increase control or reduce picloram rates proportionately on huisache, honey mesquite and live oak (*Quercus virginiana* Mill.).

Introduction

Herbicide combinations are widely used in agronomic and horticultural crops[3] and will continue to receive much attention in weed research in the future. Likewise the use of herbicide mixtures for woody plant control sometimes may be more effective than single herbicides. For example, Robison (6) found that combinations of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) plus 4-amino-3,5,6-trichloropicolinic acid (picloram) at equivalent rates on honey mesquite (*Prosopis juliflora* (Swartz) DC., var. *glandulosa* (Torr.) Cockerell) killed more roots than 2,4,5-T or picloram alone. Studies[4] on control of winged elm (*Ulmus alata* Michx.) in Oklahoma indicated additions of picloram, 3-amino-1,2,4-triazole (amitrole), and ammonium thiocyanate to 2,4,5-T increased its effectiveness.

Herbicide combinations often can broaden the spectrum of effectiveness where resistant species occur in mixed stands of brush. Kirch and Esposito (4) showed that the addition of herbicides such as picloram and amitrole to invert emulsions of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-T improved control of some woody species resistant to phenoxy herbicides.

Although apparent interactions have been reported (4, 6), our knowledge is still rudimentary. It is difficult to predict with accuracy the response of a given species to a herbicide combination. The studies reported in this paper were conducted to determine the effect of 2,4,5-T and 1,1'-dimethyl-4,4'-bipyridinium salt (paraquat) on the herbicidal properties of picloram on greenhouse, nursery, and natural-grown, woody plants and to develop a system for evaluating and predicting the effectiveness of herbicide mixtures.

Materials and Methods

Field studies. All herbicides were sprayed on 22 by 100 or 200-ft long plots in duplicate with a truck mounted sprayer (5). Herbicides were applied in water at 10 or 20 gpa at 30 psi. A surfactant containing alkylaryl polyoxyethylene glycols, free fatty acids, and isopropanol was added at 0.5% (v/v) of the spray solution.

Herbicides used in all studies included the potassium salt of picloram, 2-ethylhexyl ester of 2,4,5-T the triethylamine salt of 2,4,5-T, and paraquat. Herbicidal rates and dates of application are given later.

Wild stands of brush, 6 to 12 ft in height, were sprayed. Woody plants included yaupon (*Ilex vomitoria* Ait), live oak (*Quercus virginiana* Mill.), and huisache (*Acacia farnesiana* (L.) Willd.) at College Station, Victoria, and Refugio, Texas, respectively. Representative mixed hardwood species at Livingston, Texas, were sumac (*Rhus* spp.), sassafras (*Sassafras albidum* (Nutt.) Nees), American beech (*Fagus grandifolia* Ehrh.), Allegheny chinquapin (*Castanea pumila* (L.) Mill.), saw greenbriar (*Smilax bona-nox* L.), and sweetbay magnolia (*Magnolia virginiana* L.).

Herbicidal effectiveness was measured by estimating percentage defoliation 1 or more years after treatment.

Nursery studies. Woody plants (12 to 15 months old and 2 to 5 ft in height) were grown in a nursery near Bryan, Texas. Live oak, huisache, honey mesquite, and winged elm were sprayed with a tractor-mounted, compressed-air sprayer. Four replications with five plants per replication were treated in a randomized block design. The same surfactant and concentration was used as indicated in the field studies. Herbicides were applied in water equivalent to 20 gpa. Control evaluations were made by estimating percentage defoliation 1 year after treatment.

Greenhouse studies. Similar herbicide combinations as used in the field and nursery were applied to greenhouse-grown plants. All herbicides were applied in water equivalent to 10 gpa with a 0.5% (v/v) surfactant described under field studies. A laboratory sprayer described by Bouse and Bovey (1) was used to treat five or six plants per treatment. Herbicidal evaluations were made by estimating percentage defoliation 1 to 2 months after treatment.

Evaluation of antagonism and synergism. If a combination of two herbicides gave 20% or more defoliation than a single herbicide of the combination at equivalent rates, the mixture was considered synergistic, and if 20% or less, antagonistic. For example, if picloram at 1 lb/A produced 60% defoliation and picloram + 2,4,5-T at 1 +

[1]Received for publication October 26, 1967. Cooperative investigations of the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture and Texas A & M University. This research was supported by the Advanced Research Projects Agency, Department of Defense.

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[3]U.S. Department of Agriculture, Agricultural Research Service, Crops Research Division, 1967. Suggested guide for weed control. Agr. Handbook No. 332. U.S. Government Printing Office, Wash., D.C. 64 p.

[4]Elwell, H. M. 1967. Winged elm control with picloram and 2,4,5-T with additives. WSA Abstr. p. 24.

1 lb/A produced 80% or more defoliation, the combination was considered synergistic. However, if picloram at 1 lb/A gave 60% defoliation and picloram + paraquat at 1 + 1 lb/A produced 40% or less defoliation, the mixture was antagonistic. This procedure was used for all field, nursery, and greenhouse studies. This method was compared with one proposed by Gowing (3) and later by Colby (2) in which a formula is used to obtain an expected value of control for herbicide combinations. When the observed value is greater than expected, the combination is synergistic; when less, it is antagonistic. In general, the methods agree except that the procedure outlined in this paper is simple and more conservative.

Results

Field studies. By definition, a combination of picloram + paraquat was synergistic when applied to yaupon in April and May, 1964 (Table 1). Although not synergistic, a similar relationship was found for the June, 1965 treatment to live oak and the April, 1964 and 1965, and May, 1965, treatments on several hardwood species at Livingston, Texas. Examples of antagonism between picloram and paraquat, however, were observed in the April treatment of live oak, the April and May treatments of huisache and a July treatment of mixed hardwoods in east Texas.

In no case were combinations of picloram + 2,4,5-T antagonistic in response and they usually were more effective than either herbicide alone at equal rates. Synergism was evident in the May and the April, 1966 treatments on huisache and hardwood species, respectively.

Nursery studies. Mesquite was treated at five dates in the spring of 1965 (Table 2). Except for early in April, the addition of paraquat to picloram greatly reduced its effectiveness. For example, the June 8, 1965, treatments with picloram at 1 lb/A produced 82% defoliation, whereas those with picloram + paraquat at 1 + 1 lb/A showed only 48% defoliation 1 year after treatment. In 1966, the addition of ester or amine formulations of 2,4,5-T showed neither antagonism nor synergism, since picloram was very effective at all rates used. However, it appears that 2,4,5-T could be substituted for equal rates of picloram on mesquite since picloram plus 2,4,5-T at ¼ + ¼ lb/A was as effective as picloram or 2,4,5-T at ½ lb/A.

The addition of 2,4,5-T to picloram did not improve control of winged elm (Table 2). Control of winged elm with 2,4,5-T was not effective and 2,4,5-T could not be substituted for equal rates of picloram. Conversely, both ester and amine formulations of 2,4,5-T gave a synergistic effect with picloram when applied on live oak. Rates of picloram + 2,4,5-T at 2 + 2 lb/A gave 100% defoliation 1 year after treatment, whereas picloram at 2 lb/A produced 48% defoliation. Picloram + 2,4,5-T at 1 + 1 lb/A, using either amine or ester formulations of 2,4,5-T, were more effective than picloram alone at 2 lb/A. Picloram:2,4,5-T combinations on huisache suggested substitution of 2,4,5-T for equal rates of picloram in a picloram:2,4,5-T mixture.

Greenhouse studies. Initial studies were conducted with huisache to determine the effectiveness of herbicide mixtures (Table 3). Paraquat was antagonistic to picloram when 1:1 ratios of the chemicals were used. The antagonistic effect disappeared when higher amounts of picloram were used in the ratio (3:1).

Picloram + 2,4,5-T at 1/16 + 1/16 lb/A were as effective as picloram at ⅛ lb/A; 2,4,5-T at ⅛ lb/A was ineffective. Picloram + 2,4,5-T at 1/32 + 3/32 and 3/32 + 1/32 (3:1) were less effective than the 1:1 ratio.

Table 1. Percentage defoliation of woody plants after treatment with picloram, paraquat, 2,4,5-T, and combinations of picloram plus paraquat or 2,4,5-T.

Species and treatment date	Years after treatment	Picloram				Paraquat			2,4,5-T			Picloram + paraquat				Picloram + 2,4,5-T			Mixture response[b]	
		1[a]	2	4	8	2	4	8	2	4	8	1 + 1	4 + 4	2 + 4	4 + 2	1 + 1	2 + 2	4 + 4	Picloram + Paraquat	Picloram + 2,4,5-T
Yaupon																				
April 1964	2			40	100		10	10					100						S	
June 1964	2			35	65		15	5					85						S	
Running live oak																				
April 1964	3			50			0						20						A	
June 1965	2			78	95		35	30		45	25		88					88	ND	ND
June 1966	1		88	99													96			ND
Huisache																				
April 1964	3			40			18	30					15						A	
May 1965	2	38	85			18			20			13				88			A	S
Oct 1964	2	68	93													60				ND
Mixed hardwoods																				
April 1964	2			85	95		3	18					88						ND	
July 1964	2			60	75		0						15						A	
April 1965	2		58	75									80		80				ND	
May 1965	2		42	70									79	86					ND	
Aug 1965	1		65	60									65	55					ND	
April 1966	1		30	75					28	33							92			S

[a]Lb/A.
[b]A = Antagonism; S = Synergism; ND = No difference.

Table 2. Percentage defoliation of nursery grown woody plants 1 year after treatment with picloram, 2,4,5-T, paraquat, and mixtures of picloram, plus 2,4,5-T or paraquat.

Species and Treatment Date	Picloram ½[a]	Picloram 1	Picloram 1½	Picloram 2	Picloram 3	Picloram 4	2,4,5-T ester ½	2,4,5-T ester 1	2,4,5-T ester 1½	2,4,5-T ester 2	2,4,5-T ester 3	2,4,5-T ester 4	2,4,5-T amine ½	2,4,5-T amine 1	2,4,5-T amine 1½	2,4,5-T amine 2	2,4,5-T amine 3	2,4,5-T amine 4	Paraquat ½	Paraquat 1	Paraquat 2
Mesquite																					
April 16, 1965	29	33	—	40															25	40	43
April 30, 1965	48	55	—	84															16	17	28
June 8, 1965	75	82	—	95															12	34	43
June 30, 1965	46	78	—	95															13	13	13
July 20, 1965	48	68	—	84															18	3	27
Mesquite																					
June 29, 1966	98	100	—	98			95	99	—	100			98	93	—	99					
July 22, 1966	97	100	—	100			93	97	—	100			97	100	—	95					
Winged elm																					
May 9, 1966		66	78	96				15		15	30										
May 31, 1966		41	68	89				8		25	28										
Live oak																					
June 9, 1966				48	—	100				15		15				20		66			
Huisache																					
June 10, 1966				100	—	100				85		99				45		28			

Species and treatment date	Picloram + 2,4,5-T ester ¼ + ¼	Picloram + 2,4,5-T ester ½ + ½	Picloram + 2,4,5-T ester 1 + 1	Picloram + 2,4,5-T ester 1½ + 1½	Picloram + 2,4,5-T ester 2 + 2	Picloram + 2,4,5-T amine ¼ + ¼	Picloram + 2,4,5-T amine ½ + ½	Picloram + 2,4,5-T amine 1 + 1	Picloram + 2,4,5-T amine 2 + 2	Picloram + paraquat ¼ + ¼	Picloram + paraquat ½ + ½	Picloram + paraquat 1 + 1	Mixture response[b] Picloram + 2,4,5,T ester	Mixture response[b] Pic + 2,4,5-T amine	Mixture response[b] Picloram + Paraquat
Mesquite															
April 16, 1965										38	33	40			ND
April 30, 1965										12	28	20			A
June 8, 1965										25	33	48			A
June 30, 1965										20	15	33			A
July 20, 1965										18	25	40			A
Mesquite															
June 29, 1966	99	100	100			93	97	97					ND	ND	
July 22, 1966	95	100	100			97	94	100					ND	ND	
Winged elm															
May 9, 1966		15	58	80									ND		
May 31, 1966		30	55	60									ND		
Live oak															
June 9, 1966			75	--	100			83	100				S	S	
Huisache															
June 10, 1966			100	—	100			100	100				ND	ND	

[a]Lb/A.
[b]A = Antagonism; S = Synergism; ND = No Difference.

Table 3. Percent defoliation of greenhouse grown huisache 2 months after treatment with 2,4,5-T, paraquat, picloram, and combinations of picloram plus paraquat or 2,4,5-T.

Herbicide	Rate (lb/A)	Ratio	Percent defoliation
2,4,5-T	1/8		54
2,4,5-T	1/2		79
Paraquat	1/8		7
Paraquat	1/2		68
Picloram	1/8		100
Picloram	1/2		100
Picloram + paraquat	1/16 + 1/16	(1:1)	59
Picloram + paraquat	1/32 + 3/32	(1:3)	58
Picloram + paraquat	3/32 + 1/32	(3:1)	98
Picloram + paraquat	1/4 + 1/4	(1:1)	78
Picloram + paraquat	1/8 + 3/8	(1:3)	91
Picloram + paraquat	3/8 + 1/8	(3:1)	100
Picloram + 2,4,5-T	1/16 + 1/16	(1:1)	100
Picloram + 2,4,5-T	1/32 + 3/32	(1:3)	63
Picloram + 2,4,5-T	3/32 + 1/32	(3:1)	69
Picloram + 2,4,5-T	1/4 + 1/4	(1:1)	100
Picloram + 2,4,5-T	1/8 + 3/8	(1:3)	100
Picloram + 2,4,5-T	3/8 + 1/8	(3:1)	100

Additional greenhouse experiments conducted are presented in Table 4. Antagonism against picloram by the addition of paraquat was common on huisache and mes-

Table 4. Response of huisache and mesquite 1 to 2 months after treatment with combinations of picloram plus paraquat or 2,4,5-T compared with picloram alone at comparable rates.

Herbicide treatment	Rate (lb/A)		Huisache 1[a]	Huisache 2	Huisache 3	Mesquite 1	Mesquite 2	Mesquite 3
Picloram + paraquat	1/64 + 1/64	(1:1)	A	ND	A	ND	ND	A
Picloram + paraquat	1/128 + 3/128	(1:3)	ND	ND	ND	A	ND	A
Picloram + paraquat	3/128 + 1/128	(3:1)	A	ND	A	A	ND	ND
Picloram + paraquat	1/16 + 1/16	(1:1)	ND	ND	ND	ND	A	ND
Picloram + paraquat	1/32 + 3/32	(1:3)	S	A	A	S	A	A
Picloram + paraquat	3/32 + 1/32	(3:1)	ND	ND	ND	A	ND	ND
Picloram + 2,4,5-T	1/64 + 1/64	(1:1)	A	—	—	ND	—	—
Picloram + 2,4,5-T	1/128 + 3/128	(1:3)	ND	—	—	ND	—	—
Picloram + 2,4,5-T	3/128 + 1/128	(3:1)	ND	—	—	ND	—	—
Picloram + 2,4,5-T	1/16 + 1/16	(1:1)	ND	—	ND	S	ND	ND
Picloram + 2,4,5-T	1/128 + 3/128	(1:3)	S	—	ND	A	ND	ND
Picloram + 2,4,5-T	3/128 + 1/128	(3:1)	ND	—	ND	A	ND	ND

[a]Three separate experiments per species, one per column.
[b]A = Antagonism; S = Synergism; ND = No difference.

quite; synergism was uncommon. On the other hand, antagonism was uncommon when combinations of picloram + 2,4,5-T were used. Greenhouse-grown woody species provide a valuable system to study herbicide combinations, since greenhouse grown plants give similar herbicidal responses as field plants and permit large numbers of treatments to be evaluated in a much shorter period of time. Herbicide rates, however, for greenhouse-grown plants may be reduced in the range of 4 to 16 times to give comparable control to field species, depending upon the species and stage of growth.

Discussion

Herbicide combinations have certain advantages on resistant species and mixed stands of woody plants as encountered in many areas of the world. More species may be effectively controlled, overall herbicide rates may be reduced, and herbicide residues in plants and soils may be reduced by partially substituting effective herbicides with shorter residual characteristics. In this study, herbicide combinations were limited to paraquat or 2,4,5-T in combination with picloram. In some cases, picloram:paraquat mixtures improved control (yaupon, live oak, and several hardwood species) when compared to picloram alone. However, the addition of paraquat to picloram was definitely antagonistic (huisache and mesquite) on some species or some dates of application. Combinations of picloram:2,4,5-T were sometimes synergistic and suggested that 2,4,5-T could be added to reduce picloram rates and increase the effectiveness on some woody plants. Both ester and amine forms of 2,4,5-T were equally effective when applied in conjunction with picloram but sometimes very ineffective when applied alone on some species.

These studies strongly indicate that knowledge concerning species to be controlled, herbicide rates and ratios, and date of application are important factors in obtaining optimum results with herbicide combinations. Greenhouse and nursery-grown woody plants are useful tools in obtaining prior knowledge and predicting the best herbicide combinations to use on wild stands.

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