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Effect of Aerially-Applied Herbicides on Texas and Puerto Rico Forests[1]

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Abstract. We applied (2,4-dichlorophenoxy)acetic acid (2,4-D), (2,4,5-trichlorophenoxy)acetic acid (2,4,5-T), 4-amino-3,5,6-trichloropicolinic acid (picloram), and 1,1'-dimethyl-4,4'-bipyridinium ion (paraquat) alone and in various combinations by aircraft on arborescent species in Texas and Puerto Rico. Paraquat defoliated trees rapidly but did not give long-term control. Picloram defoliated a greater number of species than the other herbicides and defoliation extended over a longer period. No treatment killed all trees in the mixed forest or prevented regrowth and secondary succession for a period of more than 1 year. Higher herbicide rates were necessary to defoliate woody plants in tropical Puerto Rico than in subtropical Texas.

INTRODUCTION

SEVERAL herbicides were evaluated as foliage and soil treatments for the control of woody plants in Texas and Puerto Rico (1, 2, 3, 4, 7). These studies showed that (2,4-dichlorophenoxy)acetic acid (2,4-D), (2,4,5-trichlorophenoxy)-acetic acid (2,4,5-T), 4-amino-3,5,6-trichloropicolinic acid (picloram), and 1,1'-dimethyl-4,4'dipyridinium ion (paraquat), alone or in various combinations, defoliated or killed a broad spectrum of tropical and subtropical woody plants. Aerial applications of these herbicides were necessary to provide recommendations on a woody plant control program. The use of aircraft for applying herbicides in woody plant control is a standard practice because large areas can be effectively treated in a short time. Treatment of tall, dense vegetation on rough topography requires aerial application techniques.

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The objectives of this study were (a) to evaluate different rates and combinations of herbicides for their effectiveness in defoliating and killing woody plants; (b) to compare herbicides showing greatest potential with a 1:1 mixture of 2,4-D:2,4,5-T; and (c) to observe the short-term effects of these treatments on secondary plant succession.

MATERIALS AND METHODS

Test sites in Texas were located in a coastal stand of live oak (*Quercus virginiana* Mill.) near Tivoli, and a pine-hardwood forest near Legget with mean annual rainfall of 35 to 40 and 45 to 50 inches, respectively (8). The two test sites in Puerto Rico were in the Lower Cordillera near Maricao, and in the Evergreen Rain Forest of the Lower Luquillo zone (5). The mean annual rainfall on these Puerto Rican test sites is approximately 100 inches. All treatments in Texas were applied with fixed-wing aircraft delivering 1.5, 3.0, or 5.0 gpa in a 40-ft spray swath at 80 or 90 mph. All treatments in Puerto Rico were applied with a Hughes 300[4] helicopter delivering 1.5 or 3.0 gpa in a 35-ft spray swath at 45 mph. All applications were made near tree-top level.

The following herbicide formulations were used in addition to paraquat: 2 lb/gal K salt of picloram; mixture of 4 lb/gal propylene glycol butyl ether esters of 2,4,5-T plus 1 lb/gal isoocotyl ester of picloram (hereinafter referred to as 2,4,5-T:picloram); mixture of 2 lb/gal n-butyl ester of 2,4-D plus 2 lb/gal n-butyl ester of 2,4,5-T plus 1 lb/gal isocotyl ester of picloram (hereinafter referred to as 2,4-D:2,4,5-T:picloram); 4 lb/gal n-butyl ester of 2,4-D plus 4 lb/gal n-butyl ester of 2,4,5-T (hereinafter referred to as 2,4-D:2,4,5-T); and 2 lb/gal triisopropanolamine of 2,4-D plus 0.5 lb/gal triisopropanolamine of picloram (hereinafter referred to as 2,4-D:picloram). All concentrations are expressed as acid equivalents. All herbicide treatments were applied

undiluted except picloram was applied in water and 2,4-D:2,4,5-T:picloram in diesel oil on live oak at Tivoli, Texas and 2,4-D:2,4,5-T:picloram in diesel oil on Luquillo National Forest in Puerto Rico.

A randomized block design with one or two replications was used in each test. Land availability, topography, number of treatments, and application equipment determined the number of replications and plot size and are discussed under each separate test. Data were collected from marked plants in a belt transect located diagonally across each treated plot. Percentage defoliation was estimated periodically after treatment. Defoliation, calculated from individual plant defoliation, represents a mean percentage of the various species. In general, we collected defoliation data 1, 2, 4, 13, 26, and 52 weeks after treatment. Data herein are reported as percentage defoliation, but, throughout, there was a higher percentage defoliation than plants killed.

Results

Pine-hardwood forest near Legget, Texas. We applied treatments with an "Ag Cat"[4] fixed wing aircraft on single 200 by 900-ft plots as undiluted sprays (Table 1).

Table 1. Percentage defoliation following treatments May, 1966, on pine-hardwood forest near Legget, Texas.

Herbicide	Per A		Defoliation after treatment				
	gal	lb	1 wk	2 wk	4 wk	3 mo	1 yr
Paraquat	1.5	3	50	50	50	20	10
	3.0	6	30	30	40	40	10
	6.0	12	30	30	40	20	5
2,4, 5-T:picloram	1.5	7.5	10	20	40	95	70
	3.0	15	10	30	50	95	90
	6.0	30	20	35	60	95	99
Picloram	1.5	3	10	20	30	90	50
	3.0	6	10	20	40	95	85
	6.0	12	10	35	60	95	90
2, 4-D:2, 4, 5-T	1.5	12	10	30	50	90	50
	3.0	24	20	40	60	95	50
	6.0	48	20	40	70	95	95

The aircraft was calibrated to deliver 1.5 gpa. The 3.0 and 6.0-gpa rates were obtained by double and quadruple coverage.

The dominate species in the pine-hardwood forest were white ash (*Fraxinus americana* L.), sweetgum (*Liquidambar styraciflua* L.), bitternut hickory (*Carya cordiformis* (Wangenh.) K. Koch., and eastern hophornbean (*Ostrya virginiana* (Mill.) K. Koch.), but boxelder (*Acer negundo* L.), black willow (*Salix nigra* March.), American sycamore (*Plantanus occidentalis* L.), redbay (*Persea borbonia* (L.) Spreng.), and loblolly pine (*Pinus taeda* L.) also were present.

Paraquat defoliated trees faster than the other herbicides. However, 3 months after application, paraquat was the only herbicide that did not provide plot defoliation of at least 90%. A heavy rain 2 hr after the application of 3.0 and 6.0 gpa of paraquat may have affected the results of these treatments. Paraquat apparently was not mobile within the plant because the tops of trees were defoliated, but the lower branches remained green.

The herbicide mixture 2,4-D:2,4,5-T defoliated trees faster than 2,4,5-T:picloram or picloram. One year after treatment, the plot defoliation by 2,4,5-T:picloram and 2,4-D:2,4,5-T at 6.0 gpa was 99 and 95%, respectively. Defoliation resulting from 2,4,5-T:picloram at 3.0 gpa and picloram at 3.0 and 6.0 gpa was essentially the same 1 year after treatment. Also, picloram at 1.5 gpa defoliated the same percentage of trees as 2,4-D:2,4,5-T at 1.5 and 3.0 gpa.

The rates used in this test were higher than is normally required for control of these mixed hardwoods. However, white ash, bitternut hickory, and redbay were not controlled by picloram. Some tolerance to picloram also was exhibited by sweetgum. Loblolly pine was more susceptible to picloram than 2,4-D:2,4,5-T. Considering all species, 2,4,5-T:picloram was the most effective herbicide.

Live Oak near Tivoli, Texas. We applied the herbicide treatments at Tivoli with a Snow Model S2C[4] fixed wing aircraft on duplicate 200 by 1000-ft plots. The equipment was calibrated to deliver 1.5, 3.0, or 5.0 gpa and the herbicides were applied undiluted or diluted as noted in Table 2. Severe weather prevented data collection 1 year after treatment, but observations were made 23 months after application.

Table 2. Percentage of desiccation and defoliation following treatments November, 1966, on live oak near Tivoli, Texas.

Herbicide	Per A		Desiccation and defoliation after treatment[a]				
	gal	lb	1 wk	2 wk	4 wk	5 mo	23 mo
2, 4-D:2,4,5-T:picloram	1.5	7.5	29/0	88/15	95/78	70	5
2, 4-D:2,4,5-T:picloram	3.0	15	46/0	85/45	99/62	82	20
2, 4-D:2,4,5-T:picloram + oil (1 + 1)[b]	3.0	7.5	21/0	93/45	97/85	81	15
Picloram + water (1 + 4)[c]	5.0	2	18/0	90/25	94/82	91	65
2, 4-D:2,4,5-T	3.0	24	26/0	95/62	98/80	80	25

[a]The number to the left of the slant mark is percentage desiccation and defoliation; that to the right is percentage defoliation. Single numbers are defoliation only.
[b]Aromatic naptha oil.
[c]0.5% X-77 surfactant (alkylarylpolyoxyethylene glycols, free fatty acids, isopropanol) added.

The herbicide mixture 2,4-D:2,4,5-T:picloram at 3.0 gpa desiccated 46% of the leaves 1 week after treatment, but average desiccation from all treatments was at least 85% after 2 weeks. Four weeks after application, all treatments had a mean desiccation of 94 to 99%, but 2,4-D:2,4,5-T:picloram at 3.0 gpa did not cause as much defoliation as the other treatments. Five and 23 months after application, picloram was more effective than the other treatments. The data in Table 2 also indicate that the addition of an oil carrier to 2,4-D: 2,4,5-T:picloram slightly increased activity. This may have resulted from phytotoxic properties of the oil and increased volume per acre.

Evergreen Rain Forest, Lower Luquillo, Puerto Rico (Test 1). Herbicides were applied with a helicopter calibrated to deliver 1.5 or 3.0 gpa. Six gpa were applied by spraying each swath on a plot twice at 3.0 gpa. Duplicate 175 by 249-ft (1 A) plots were treated April 1, 1966 with undiluted paraquat, 2,4,5-T: picloram, 2,4-D: 2,4,5-T, and picloram (Table 3).

[4]Trade names or code numbers are used in this publication solely for the purpose of identification and simplicity. Their mention does not constitute a guarantee or a warranty of the product by the U. S. Department of Agriculture or an endorsement by the Department over other products of a similar nature not mentioned.

Table 3. Percentage desiccation and defoliation following treatments April, 1966, in Luquillo National Forest, Puerto Rico.

Herbicide	Per A		Desiccation and defoliation following treatment[a]					
	gal	lb	1 wk	2 wk	4 wk	3 mo	6 mo	1 yr
Paraquat.....	1.5	3	15/9	25/18	27/25	19	9	10
	3.0	6	29/13	51/29	68/63	51	41	31
	6.0	12	38/23	53/35	60/56	43	15	17
2,4,5-T:picloram...	1.5	7.5	7/0	25/14	42/39	52	40	45
	3.0	15	3/0	25/5	39/32	42	46	51
	6.0	30	7/0	38/13	62/45	77	73	69
Picloram.....	1.5	3	8/0	24/14	34/32	29	27	30
	3.0	6	8/0	51/21	70/52	80	60	55
	6.0	12	19/9	51/22	78/66	83	76	75
2,4-D:2,4, 5-T.....	1.5	12	9/3	53/28	69/61	65	52	38
	3.0	24	19/8	73/32	89/73	79	66	55
	6.0	48	28/10	79/37	89/75	91	71	61

[a]The number to the left of the slant mark is percentage desiccation and defoliation; that to the right is perventage defoliation. Single numbers are defoliation only.

One week after treatment, paraquat at 6.0 gpa had desiccated more leaves and defoliated more trees than any other treatment. The herbicide mixture 2,4-D:2,4,5-T desiccated and defoliated more trees than the other herbicides 2 weeks after application and maintained this superiority through 4 weeks. Maximum defoliation from paraquat was obtained 4 weeks after treatment, but maximum defoliation from the other herbicides did not occur until 3 months after application. Also, 2,4-D:2,4,5-T caused more defoliation than paraquat, picloram, and 2,4,5-T:picloram at equivalent volumes 3 months after treatment. Recovery between 3 and 6 months after treatment, expressed as the difference in percentage defoliation for the two dates, with the 6.0-gpa volumes, was 20% for 2,4-D:2,4,5-T, 7% for picloram, and 4% for 2,4,5-T:picloram. These data indicate that the addition of picloram to phenoxy herbicides reduces regrowth of trees. The regrowth of woody species was always greater where treatments contained only phenoxy herbicides than when the treatments contained picloram. One year after treatment, picloram at 3.0 gpa was as effective as 2,4-D:2,4,5-T or 2,4,5-T:picloram at 3.0 gpa. Picloram was the most effective herbicide in this test on a lb/A basis.

Although data on individual species susceptibility were not tabulated, general observations indicated that *Tabebuia heterophylla* (DC.) Britton was more resistant to the herbicide treatments than any other species present.

Succession of other species or seedlings of the same species was evident 6 months after treatment. Succession appeared to be positively related to defoliation but not to herbicide treatment. Plots with the highest percentage defoliation also had the highest density of invading species. Grasses, sedges, vines, and other herbaceous plants were most evident initially (6 months) after treatment; but three seedlings, represented by *Cecropia peltata* L., *Didymopanax mortotoni* (Aubl.) Decne. & Planch., and *Psychotria berteriana* DC. were common 1 year after treatment. The U. S. Forest Service also planted teak (*Tectonia grandis* L.) and mahogany (*Swietenia mahagoni* Jacq.) on our plots, beginning approximately 1 week after application. These species were not affected by the herbicide treatments and were surviving 1 year after planting.

Evergreen Rain Forest, Lower Luquillo, Puerto Rico Forest (Test II). The same type of equipment and application procedures were used as in the preceding test, except that single 210 by 622-ft (3 A) plots were treated. Climatic conditions were favorable when the treatments were applied, but rain occurred within 1 hr after the applications were completed. An estimated 2 inches of rain fell during the next 24 hr.

Picloram at 3 gpa was the fastest-acting and most effective long-term treatment in this test (Table 4). One

Table 4. Percentage of desiccation and defoliation following treatments October, 1966, in Luquillo National Forest, Puerto Rico.

Herbicide	Per A		Desiccation and defoliation following treatments[a]					
	gal	lb	1 wk	2 wk	4 wk	3 mo	6 mo	1 yr
2,4-D:2,4,5-T:picloram ..	1.5	7.5	0/0	6/4	4/3	6/6	11	9
2,4-D:2,4,5-T:picloram + diesel oil (1+1).....	3.0	7.5	0/0	27/13	50/41	53/48	58	51
2,4-D:2,4,5-T:picloram ..	3.0	15	0/0	28/15	49/47	72/68	78	69
Picloram.....	3.0	6	15/6	46/26	75/60	88/84	85	88
2,4,5-T:picloram.....	3.0	15	1/0	35/17	70/52	86/79	86	85
2,4-D:2,4,5-T.....	3.0	24	3/1	35/20	61/46	68/62	75	70

[a]The number to the left of the slant mark is percentage desiccation and defoliation; that to the right is percentage defoliation. Single numbers are defoliation only.

week after application, picloram had desiccated 15% of the leaves on the trees as compared to 3% for 2,4-D:2,4,5-T. Defoliation 1 month after treatment was essentially the same for 2,4-D:2,4,5-T:picloram, 2,4,5-T:picloram, and 2,4-D:2,4,5-T at 3.0 gpa. Three months after treatment the percentage defoliation caused by 2,4,5-T:picloram and picloram at 3.0 gpa were nearly equal. The percentage defoliation caused by 2,4-D:2,4,5-T:picloram and 2,4-D:2,4,5-T at 3.0 gpa was similar but about 15% less than the defoliation caused by 2,4,5-T:picloram and picloram at comparable volumes. This was also true 1 year after treatment. One year after application, the mean defoliation from all treatments except 2,4-D:2,4,5-T:picloram at 1.5 gpa was more than 50%.

The 2,4-D:2,4,5-T:picloram at 1.5 gpa caused only a low percentage of defoliation. When 1.5 gal of 2,4-D:2,4,5-T:picloram were combined with 1.5 gal diesel oil, however, the percentage of defoliation was markedly increased.

We identified and tagged more than 40 species in the test area of the Evergreen Rain Forest. The differential species susceptibility of the six major species 1 year after treatment is recorded in Table 5. These species represent 38% of the population on which defoliation data were recorded. Some of the problems involved

Table 5. Percentage of defoliation of the six principal species 1 year after treatment October, 1966, in Luquillo National Forest, Puerto Rico.

Herbicide	Per A		Defoliation of species in order of decreasing importance					
	gal	lb	1	2	3	4	5	6
2,4-D:2,4,5-T:picloram....	1.5	7.5	3	2	0	0	100	6
2,4-D:2,4,5-T:picloram + diesel oil (1+1).....	3.0	7.5	39	29	7	72	87	57
2,4-D:2,4,5-T:picloram....	3.0	15	74	28	35	99	100	—
Picloram.....	3.0	6	90	77	45	65	100	100
2,4,5-T:picloram.....	3.0	15	100	82	38	—	100	90
2,4-D:2,4,5-T.....	3.0	24	65	59	23	63	100	79

[a]1. *Prestoea montana* (Graham) Nicholson. 2. *Casearia sylvestris* Sw. 3. *Tabebuia heterophylla* (DC.) Britton. 4. *Didymopanax morototoni* (Aubl.) Decne & Planch. 5. *Myrcia splendens* (Sw.) DC. 6. *Inga fagifolia* (L.) Willd.

in evaluating herbicides in tropical forest have been discussed previously (6).

Tabebuia heterophylla (DC.) Britton was the most resistant species and *Myrcia splendens* (Sw.) DC. was the most susceptible species in this test. Although there was a wide range of susceptibility, picloram and 2,4,5-T: picloram caused the highest percentage defoliation of the major species present. These data also suggest that 2,4-D is not as effective on a mixed tropical forest as either 2,4,5-T or picloram.

Secondary succession occurrred as in the previous test.

Semievergreen Forest, Lower Cordillera near Maricao, Puerto Rico. Another aerial application was made in a mixed semievergreen forest in August, 1966, using the same equipment as in the preceding test, except that the plot size was 175 by 745 ft.

Two and 4 weeks after application, 2,4,5-T:picloram at 6 gpa and 2,4-D: 2,4,5-T at 3.0 gpa were equally effective (Table 6). Six months and 1 year after treatment, 2,4,5-T:picloram at 6 gpa was the most effective treatment in this test.

Table 6. Percentage desiccation and defoliation resulting following 1966 treatment in Lower Cordillera forest, Puerto Rico.

Herbicide	Per A		Desiccation and defoliation following treatment[a]					
	gal	lb	1 wk	2 wk	4 wk	3 mo	6 mo	1 yr
2,4,5-T:picloram	6	30	0/0	26/8	67/50	80/79	83	77
Picloram	3	6	0/0	29/19	43/38	51/50	48	52
2,4-D:picloram	6	15	0/0	35/15	57/37	53/47	52	51
2,4-D:2,4,5-T + picloram (1+2)	3	12	0/0	26/14	44/32	52/48	57	63
2,4-D:2,4,5-T	3	24	0/0	30/8	63/48	73/71	61	64

[a]The figure to the left of the slant mark is percentage desiccation and defoliation; that to the right is percentage defoliation. Single figures are defoliation only.

Picloram, 2,4-D:2,4,5-T, and a mixture of 2,4-D:2,4,5-T + picloram (1+2) at 3.0 gpa were as effective as 2,4-D:picloram at 6.0 gpa. One year after application, 2,4-D:2,4,5-T and a mixture of 2,4-D:2,4,5-T + picloram (1+2) at 3.0 gpa were more effective than picloram or a mixture of 2,4-D:picloram.

The defoliation data from this test were recorded for more than 30 species. The susceptibility of the seven major species recorded in Table 7 represents 73% of the total woody plant population in our sampling area. *Guarea trichiliodes* L. was the most resistant species to the treatments in this test. *Inga vera* Willd. and *Dendropanax arboreus* (L.) Decne. & Planch. were more susceptible to the treatments than the other species. *Guarea trichiliodes* L. was resistant to picloram at 3 gpa and also to 2,4-D:picloram at 6 gpa. These data indicate that 2,4,5-T:picloram generally will defoliate a broader spectrum of woody plants than picloram or 2,4-D:2,4,5-T. The data from this test suggest that 2,4-D has less herbicidal activity on tropical woody plants than 2,4,5-T or picloram, and that pound for pound, picloram is the most effective herbicide on woody species.

Table 7. Percentage of defoliation of the seven principal species 1 year following 1966 treatment in Lower Cordillera forest, Puerto Rico.

Herbicide	Per A		Defoliation of species in order of decreasing importance[a]						
	gal	lb	1	2	3	4	5	6	7
2,4,5-T:picloram	6	30	78	82	83	84	94	—	76
Picloram	3	6	9	64	100	100	45	—	66
2,4-D:picloram	6	15	20	73	96	87	—	—	—
2,4-D:2,4,5-T + picloram (1+2)	3	12	40	49	97	97	74	20	34
2,4-D:2,4,5-T	3	24	53	73	79	72	81	37	65

[a]1. *Guarea trichiliodes* L. 2. *Inga fagifolia* (L.) Willd. 3. *Inga vera* Willd. 4. *Dendropanax arboreus* (L.) Decne. & Planch. 5. *Pouteria multiflora* (A. DC.) Eyma. 6. *Eugenia ambos* L. 7. *Citrus sinensis* Osbeck.

Discussion

Paraquat defoliated trees rapidly in both Texas and Puerto Rican forests. Maximum defoliation occurred 4 weeks after application and regrowth was quite evident 6 months after application. In addition, 3.0 gpa (6 lb/A) of paraquat was as effective as 6.0 gpa (12 lb/A). This suggests that paraquat is not readily mobile in woody plants, and that spray penetration and coverage through the forest canopy may be as important as the amount of material applied.

Picloram was slow-acting but defoliated a higher percentage of trees and suppressed regrowth more than any other herbicide. Picloram provided greater bud suppression than the phenoxy herbicides, an important factor because many woody species are vigorous sprouters. Although there was differential species susceptibility, picloram has a broader spectrum of activity than the phenoxy herbicides. Our data also indicate that 2,4,5-T is more effective than 2,4-D in mixed tropical and subtropical forests. In general, 2,4,5-T:picloram caused more defoliation than 2,4-D:2,4,5-T or 2,4-D:picloram.

Our results suggest differential seasonal susceptibility. Because the species composition of the two sites in Texas was different, direct comparisons cannot be made. In Puerto Rico, the data from two adjacent test sites in Luquillo Forest suggest that equivalent rates of picloram or 2,4-D:2,4,5-T were more effective when applied in October than in April (Table 3 and 4). Defoliation from applications made in August on the semievergreen forest near Maricao was intermediate (Table 6). Although extended dry periods are rare in these areas, there is less rainfall during the November-February period than for the remainder of the year. July, August, and September are the wettest months. These data suggest that after the highest defoliation has occurred (normally 3 months), the amount of regrowth is directly related to a period of high rainfall. This trend tends to support earlier conclusions (7). More years of testing are required for conclusive data.

Secondary succession is rapid and dramatic in tropical forests. Observations on succession were reported earlier (4). The same general trend was observed in the aerial tests reported herein, except that the rate of succession appeared to be more rapid than in previous tests. This was probably because the herbicide concentration on the forest floor was low, due to interception of spray by the canopy and to the fact that light penetration, which appears to be a major factor in secondary succession, was greater on the larger plot size.

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