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Influence of Adjuvants and Plant Growth Regulators on Herbicide Performance in Honey Mesquite

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Abstract. Addition of surfactant I (trimethylnonylpolyethoxyethanol) or surfactant II (4-isopropenyl-1-methyl-cyclohexane) at 1.0 and 0.6% (v/v) of the spray solution enhanced the phytotoxicity of clopyralid (3,6-dichloro-2-pyridinecarboxylic acid), the triethylamine salt of triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}, picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid), and 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid)] applied at 0.14 kg ae/ha to greenhouse-grown honey mesquite (*Prosopis glandulosa* Torr.). Application of benazolin [4-chloro-2-oxo-3(2*H*)-benzothiazolacetic acid] increased the phytotoxicity of all herbicides, but ethephon [(2-chloroethyl)phosphonic acid] and mefluidide {*N*-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino]phenyl]acetamide} were usually ineffective. Clopyralid + picloram, triclopyr, or 2,4,5-T applied in 1:1 combinations at 0.07 + 0.07 kg/ha were usually equally or more effective than any one of the herbicides applied alone at 0.14 kg/ha. Adjuvants did not enhance the phytotoxicity of picloram, triclopyr, or 2,4,5-T on field-grown honey mesquite but sometimes did with clopyralid.

Honey mesquite is a woody legume that occurs as a weed problem on several million hectares of rangeland in the southwestern U.S. (Meyer et al. 1971). Economical control of honey mesquite is sometimes difficult, because of its variable response to herbicides (Meyer and Bovey 1986). Some herbicides may

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kill most plants, but under similar conditions at another location or time, few if any plants are controlled. Some environmental factors affecting the response of honey mesquite to herbicides have been defined (Bovey and Meyer 1981, Meyer and Bovey 1986,) so that optimum herbicide, herbicide rates, and timing of application can be selected. Even with optimum application, honey mesquite control is sometimes less effective than desired. The combination of 2,4,5-T + picloram has been used commercially and is slightly more effective than 2,4,5-T alone (Bovey and Meyer 1985, Meyer and Bovey 1986). More recently clopyralid and 1:1 combinations of clopyralid + picloram or triclopyr were superior to 2,4,5-T, picloram, or triclopyr applied alone at equal rates, but any of these herbicides may have limited use because of high costs or environmental constraints. Because of environmental constraints, 2,4,5-T is no longer available, so effective alternatives are required.

Under dry environment, the addition of surfactant I (Dupont surfactant WK) or surfactant II (Cide-Kick) at 0.5% (v/v) of the spray solution or 1:1 active ingredient applications of benazolin, picloram, or triclopyr + clopyralid enhanced its phytotoxicity and transport in honey mesquite compared to clopyralid applied alone (Bovey et al. 1986b).

Plant growth regulators have had limited use in combinations with herbicides on honey mesquite, but pretreatment of ethephon increased the basipetal translocation of dicamba (3,6-dichloro-2-methoxybenzoic acid) in wild garlic (*Allium vineale* L.) (Binning et al. 1971). Mefluidide increased the amount of ^{14}C-picloram absorbed and translocated to the roots of leafy spurge (*Euphorbia esula* L.) (Regimbal and Martin, 1985).

The objectives of our research were (1) to determine if surfactants, plant growth regulators, or other herbicides increased the phytotoxicity of the most commonly used herbicides on greenhouse and field-grown honey mesquite, and (2) to develop an effective method to extend the season of application from May and June to July and August on honey mesquite.

Materials and Methods

Greenhouse Experiments

Honey mesquite plants were grown in the greenhouse for 8–10 months in 12.7 cm in diameter and 12.7 cm deep pots containing a mixture of Bleiberville clay (a member of the fine montmorillonitic, thermic Udic Pellusterts), sand, and peat moss (1:1:1, v/v/v). At time of treatment, plants had woody stems 30–40 cm tall with one primary stem per plant. One to three plants were grown per pot.

Herbicide formulations consisted of the butoxyethanol ester of 2,4,5-T or triclopyr, the triethylamine salt of triclopyr, the potassium salt of picloram, the monoethanol amine salt of clopyralid, the propylene glycol butyl ether ester of 2,4-D, and 1:1 paired combinations of all these herbicides. All herbicides were applied at sublethal rates of 0.14 kg/ha when alone or at 0.07 + 0.07 kg/ha when paired. All herbicides were applied in water at the equivalent volume of 93.5 L/ha with a laboratory spray chamber (Bouse and Bovey 1967).

Surfactant I or II was included at 0.1, 0.5, or 1.0% (v/v) the spray solution. All growth regulators were applied at 0.14 kg/ha alone or in 1:1 paired combination with herbicides. The ethyl ester or benazolin, the diethanolamine salt of mefluidide, ethephon, GAF 7767141 (GAF Corporation, New York) (ethephon + *N*-methyl-2-pyrrolidone) (2:1.4), and GAF 7863010 (*N*-methyl-2-pyrrolidone) were used.

All plants were returned to the greenhouse after treatment and were watered after 24 h and daily thereafter as needed. Care was taken to avoid aerial portions of the plant in watering the soil. Percentage of dead stem tissue on each plant was estimated 2 months after herbicide application. Plants with 100% dead stem tissue with no resprouts were considered dead. Experiments were first applied in June and then repeated in July or August of the same year. Data were pooled for presentation in this report. A randomized complete block design was used with five replications (pots) for each treatment. Data were subjected to analysis of variance, and means were compared by the $LSD_{5\%}$ value. Data were also analyzed as arcsine-transformed values, but there was no meaningful difference between the two analyses (Steel and Torrie, 1980).

Field Experiments

Honey mesquite plants 1–2 m tall growing on a Wilson clay loam (a member of the fine, montmorillomitic, thermic Vertic Ochraqualfs) were sprayed on July 8 or August 24, 1982; May 26 or August 25, 1983; and May 23 or August 10, 1984. Similar herbicides, surfactants, and plant growth regulators were used in the field as in the greenhouse except that Folicote, a nonionic paraffin wax emulsion used commercially to reduce transpiration of plants, was included with some herbicide sprays at 1% (v/v) of the spray solution. Herbicides and plant growth regulators were applied at 0.56 kg/ha alone or in paired combinations unless indicated otherwise in Tables 3 and 4. Surfactant I was added at 0.1% (v/v) of the herbicide spray solutions. All herbicides were applied in water at the equivalent volume of 187 L/ha at a pressure of 210 kPa. A hand-carried three-nozzle boom sprayer was used. Three replications per treatment with five plants per replicate were arranged in a randomized, complete block design.

Treatments were evaluated after 1 year by visually estimating the percentage canopy reduction of each plant. Plants completely defoliated with no apparent live tissue were considered dead. Data were subjected to analysis of variance, and means were compared by the $LSD_{5\%}$ value. Data were also analyzed as arcsine-transformed values, but there was no meaningful difference between the two analyses (Steel and Torrie, 1980).

Results

Greenhouse Experiments

Addition of surfactant I or II significantly enhanced the phytotoxicity of all herbicides except the ester of triclopyr on greenhouse-grown honey mesquite

(Table 1). The surfactants alone had no visible effect on honey mesquite. Other investigations (Bovey et al. 1986b,c) indicated that addition of surfactant I to clopyralid spray solutions increased both spray deposit and herbicide transport into both greenhouse and field-grown honey mesquite. A similar trend occurred for surfactant II on field-grown honey mesquite.

Plant growth regulators GAF 7863010, GAF 7767141, ethephon, or mefluidide applied with herbicides did not enhance the activity of picloram, clopyralid, or the ester of triclopyr on honey mesquite (Table 1). GAF 7767141 did enhance the activity of triclopyr amine and 2,4,5-T, as did ethephon with triclopyr amine and mefluidide with 2,4,5-T. Without adjuvants the ester of triclopyr was consistently more effective than the amine salt of triclopyr on greenhouse or field-grown honey mesquite. However, benazolin enhanced the phytotoxicity of all herbicides included in these experiments. Benazolin (Bovey et al. 1986b,c) has been shown to enhance the transport of clopyralid in honey mesquite.

GAF 7863010, GAF 7767141, ethephon, mefluidide, or benazolin was applied in 1:1 combinations with clopyralid at a rate of 0.14 + 0.14 kg/ha plus surfactant I at 1% (v/v) of the spray solution (data not shown). Surfactant II at 0.6% (v/v) of the spray solution was also combined with clopyralid and surfactant I. The phytotoxicity of the three-way combinations were usually no different from clopyralid + surfactant I alone. There was also no difference among rates of surfactant I of 0.1%, 1%, or 5% (v/v) of the spray solution. Folicote at 1% (v/v) of the spray solution did not enhance the activity of clopyralid but did enhance the activity of 2,4,5-T. Mefluidide, GAF 7767141, or surfactant II applied at 0.14 kg/ha or 0.6% (v/v) of the spray solution, respectively, 1, 3, or 7 days before 0.14 kg/ha of clopyralid or 2,4,5-T did not enhance the phytotoxicity of the herbicides on greenhouse-grown honey mesquite.

Addition of surfactant I or II at 0.1 or 0.5% (v/v) of the spray solution enhanced the activity of picloram on greenhouse-grown honey mesquite (Table 2). Also by reducing the rate of picloram by one-half and substituting clopyralid in 1:1 combination with picloram (0.07 + 0.07 kg/ha), more stem tissue was killed than with either herbicide applied alone. Addition of surfactants or growth regulators to the picloram + clopyralid combination did not enhance percentage of stem tissue killed. Surfactant I or II at 0.5% (v/v) of the spray solution or mefluidide added to clopyralid improved the killing of stems over clopyralid applied alone. Addition of the ester of triclopyr also was synergistic with clopyralid. However, none of the other adjuvants improved the performance of the ester of triclopyr over that of clopyralid + triclopyr mixture or triclopyr ester applied alone. The highly effective mixtures of clopyralid + picloram or triclopyr for control of honey mesquite is consistent with results from other studies (Bovey and Meyer 1985, Bovey et al. 1986b, Jacoby et al. 1981). Surfactant at 0.1% of the spray mixture enhanced the performance of the amine salt of triclopyr, the ester of 2,4,5-T, and 1:1 combinations of triclopyr + 2,4,5-T or triclopyr + picloram on honey mesquite. Surfactant II at 0.1 and 0.5% (v/v) of the spray mixture also enhanced the phytotoxicity of 2,4,5-T and the amine salt of triclopyr at 0.5%. Herbicide mixtures of clopyr-

Table 1. Percent stem tissue kill of greenhouse-grown honey mesquite 2 months after treatment in 1982.

	Adjuvant or growth regulator[b]							
Herbicide[a]	None	Surfactant I	Surfactant II	GAF 7863010	GAF 7767141	Ethephon	Mefluidide	Benazolin
Picloram	41	70	59	35	52	40	51	81
Clopyralid	7	73	58	9	7	28	22	58
Triclopyr (amine)	3	60	26	11	42	50	15	24
Triclopyr (ester)	65	82	83	65	60	66	69	85
2,4,5-T	19	54	72	35	47	29	46	69
None	1	1	1	6	3	7	1	3

[a] All herbicides were applied as foliar sprays at 0.14 kg/ha in water at the equivalent volume of 93.5 L/ha with a laboratory sprayer. Surfactant I or II was added at 1.0% and 0.6% (v/v) of the spray mixture; all growth regulators were applied at 0.14 kg/ha.

[b] $LSD_{5\%}$ = 19%.

Table 2. Percent stem tissue kill of greenhouse-grown honey mesquite 2 months after treatment in 1983.

	Adjuvant or growth regulator[b]							
Herbicide[a]	None	Surfactant I (0.1%)	Surfactant I (0.5%)	Surfactant II (0.1%)	Surfactant II (0.5%)	Ethephon	Mefluidide	Benazolin
Picloram	33	76	86	56	63	34	35	61
Clopyralid	55	57	96	50	81	60	79	73
Clopyralid + picloram	88	80	—	85	—	92	92	88
Clopyralid + triclopyr	89	93	—	70	—	81	83	78
Clopyralid + 2,4,5-T	75	74	—	50	—	65	90	76
Triclopyr (ester)	54	70	47	54	46	39	39	59
Triclopyr + picloram	62	91	—	66	—	79	54	58
Triclopyr (amine)	13	39	37	13	30	20	20	24
2,4,5-T	19	46	50	42	57	45	36	35
2,4,5-T + picloram	44	55	—	61	—	51	64	66
2,4,5-T + triclopyr	35	59	—	55	—	33	28	45
2,4-D	3	4	—	4	—	7	4	13
2,4-D + picloram	48	29	—	49	—	47	32	60
None	1	1	—	1	—	2	1	2

[a] All herbicides or plant growth regulators were applied as foliar sprays in water at a total of 0.14 kg/ha; paired herbicides were applied at 0.07 + 0.07 kg/ha. The butoxyethyl ester of triclopyr was used in mixtures with other herbicides.

[b] $LSD_{5\%}$ = 23%.

alid + picloram or triclopyr were superior to other herbicides and mixtures including paired combinations of picloram + 2,4,-D, 2,4,5-T, or triclopyr or triclopyr + 2,4,5-T.

Field Experiments

Neither mefluidide nor GAF 7767141 increased the percentage canopy reduction or percentage of dead plants in combination with the ester of triclopyr, the ester of 2,4,5-T, the butoxyethanol esters of 2,4,5-T + picloram, or the K salt of picloram at either application date (Table 3). However, when applied in July with clopyralid, applications of GAF 7767141, GAF 7863010, mefluidide, ethephon, surfactant II, benazolin, and Folicote increased the percentage canopy reduction of honey mesquite compared with clopyralid applied alone. More plants were also killed with most plant growth regulators when combined with clopyralid in the July but not the August 1982 treatments. Benazolin + clopyralid was especially effective in killing honey mesquite. When applied in August, surfactant II, Folicote, and GAF 7863010 with clopyralid tended to increase the percentage of dead plants over clopyralid applied alone, but the differences were not statistically significant.

Treatments made in 1983 and 1984 indicated that none of the surfactants or plant growth regulators improved phytotoxicity of 2,4,5-T, triclopyr, picloram, or clopyralid over each herbicide applied alone (Table 4). Environmental conditions including abundant soil moisture in May 1983 and 1984 were very favorable for excellent honey mesquite growth and development relative to 1982. Excellent control of honey mesquite was obtained with the herbicides at rates of 0.56 kg/ha. Clopyralid alone applied in May was especially effective by killing 94% of the plants. Clopyralid combined with surfactant II at 1.0% or surfactant I at 0.5% (v/v) of the spray solution killed all treated plants. When applied in August, a very unfavorable period for satisfactory results, differences between herbicides applied alone or with adjuvants were not apparent. Folicote applied with clopyralid tended to be more effective than clopyralid applied alone, but the difference was not significant. When clopyralid was applied in August 1983 and 1984 at 0.56 kg/ha, it killed 57% of the plants compared to 17% or less by the other individual herbicides. Clopyralid, picloram, and the ester of triclopyr were much more effective applied in May than in August.

Greenhouse-grown honey mesquite usually responds to herbicides similar to field-grown honey mesquite except that higher rates are required in the field. Field plant response, however, is sometimes variable because of differences in environment and stage of growth. The reason that field-grown plants did not respond as well as greenhouse-grown plants is not clear, but each herbicide used in the field produced maximum effect based on past data (Bovey and Meyer 1981, 1985, Meyer and Bovey 1986). Field-grown honey mesquite may have been more responsive to adjuvants combinied with sublethal herbicide rates, especially when applied in May.

Table 3. Percent canopy reduction (CR) and dead plants (DP) of field-grown honey mesquite 1 year after treatment near Bryan, Texas, in 1982.[a]

		Date applied[b]			
		7/8/82		8/24/82	
Herbicide	Adjuvant	CR	DP	CR	DP
Triclopyr +	None	52	20	43	0
	GAF 7767141	35	0	34	0
	Mefluidide	30	0	47	7
2,4,5-T +	None	45	13	49	7
	GAF 7767141	34	7	25	0
	Mefluidide	29	0	33	0
	Folicote	48	0	57	0
2,4,5-T +	None	65	27	47	0
picloram +	GAF 7767141	48	0	53	7
	Mefluidide	46	0	38	7
Picloram +	None	41	7	41	0
	GAF 7767141	43	0	36	0
	Mefluidide	45	7	43	7
Clopyralid +	None	41	0	58	7
	GAF 7767141	72	27	59	0
	Mefluidide	74	20	69	7
	Ethephon	66	13	—	—
	Surfactant II (1%)	79	33	78	20
	Surfactant II (5%)	80	40	67	13
	Benazolin	92	67	58	7
	Folicote	90	33	84	20
	GAF 7863010	74	27	73	20
Untreated	—	13	0	15	0

[a] All herbicides or herbicide mixtures were applied as foliar sprays at a total of 0.56 kg/ha. Herbicides + GAF 7863010 or mefluidide were applied at 0.56 + 0.56 kg/ha, and herbicides + GAF 7767141 were applied at 0.56 + 1 kg/ha. Folicote was applied with herbicides at 1% (v/v) of the spray mixture; surfactant II was applied 1% and 5% (v/v) of the spray mixture.

[b] $LSD_{5\%}$ for canopy reduction = 17%; $LSD_{5\%}$ for percentage of dead plants = 21%.

Discussion

The phytotoxicity of picloram, clopyralid, triclopyr, and 2,4,5-T could be consistently increased with surfactants, and benazolin in greenhouse-grown honey mesquite, but similar results were not obtained in the field except for clopyralid. Four times (0.56 kg/ha) as much herbicide was used in the field as in the greenhouse (0.14 kg/ha) applications, and lethal rates of herbicide may have partially overwhelmed the absorption/transport mechanisms. Each herbicide has different capabilities for killing honey mesquite, with clopyralid and picloram being the most effective followed by triclopyr and 2,4,5-T. Even though killing of the honey mesquite was effective in May, there were possibilities for improvement, especially in the August applications by 2,4,5-T, triclopyr, and picloram. Honey mesquite control with clopyralid in May 1983 and 1984 was outstanding. The heavier epicuticular wax on field-grown honey mesquite versus limited wax development on greenhouse-grown honey mesquite leaves

Table 4. Percent canopy reduction (CR) and dead plants (DP) of field-grown honey mesquite 1 year after treatment near Bryan, Texas, in 1983 and 1984.[a]

		Date applied[b]			
		May		August	
Herbicide	Adjuvant	CR	DP	CR	DP
2,4,5-T +	None	66	23	51	17
	Surfactant II	70	20	44	13
	Ethephon	47	7	32	4
	Mefluidide	65	20	38	4
	Surfactant I	70	30	36	7
	Folicote	66	20	42	4
Picloram +	None	90	74	44	7
	Surfactant II	95	77	44	4
	Ethephon	75	43	56	7
	Mefluidide	79	44	41	0
	Surfactant I	97	80	62	20
	Folicote	87	64	55	7
Triclopyr	None	86	40	56	10
(ester) +	Surfactant II	83	57	49	14
	Ethephon	68	24	39	0
	Mefluidide	81	44	53	7
	Surfactant I	81	37	55	7
	Folicote	74	24	55	14
Triclopyr	None	58	27	53	7
(amine) +	Surfactant II	68	20	54	10
	Surfactant I	75	24	51	10
Clopyralid +	None	99	94	91	57
	Ethephon	99	93	82	50
	Mefluidide	98	87	84	40
	Surfactant II (0.5%)	100	94	86	43
	Surfactant II (1%)	100	100	92	50
	Surfactant I (0.1%)	100	97	83	37
	Surfactant I (0.5%)	100	100	85	43
	Folicote (0.5%)	99	90	91	50
	Folicote (1%)	100	97	98	77
Untreated	—	4	0	8	0

[a] All herbicides or herbicide mixtures were applied as foliar sprays at a total of 0.56 kg/ha; herbicide + growth regulators were applied at 0.56 + 0.56 kg/ha. Surfactant I, surfactant II, and Folicote were applied with herbicides at 0.1, 1, and 1% (v/v) of the spray mixture unless otherwise indicated.

[b] $LSD_{5\%}$ for percentage canopy reduction = 17%; $LSD_{5\%}$ for percentage dead plants = 24%.

may have also caused differences in herbicide response (Mayeux and Jordan 1984, Meyer et al. 1971). However, absorption and translocation of herbicides used in this study are usually rapid and extensive in either greenhouse or field-grown honey mesquite (Bovey et al. 1983, 1986a). Herbicide transport and phytotoxicity in honey mesquite may be significantly restricted under moisture stress (Bovey and Meyer 1981, Davis et al. 1968) and in applications made late in the season—in July, August, or September (Bovey et al. 1986a, Meyer and

Bovey 1986). In our studies moisture stress did not appear to be a factor in the May applications, since adequate rainfall and soil moisture occurred immediately before and after treatment.

In this report (Table 3) and other studies (Bovey et al. 1986b), when soil moisture was inadequate for rapid growth of honey mesquite, surfactants and other herbicides increased the phytotoxicity of clopyralid compared to clopyralid applied alone by enhancing transport. Although addition of adjuvants with clopyralid sometimes increased absorption and translocation of clopyralid in honey mesquite, this did not always increase the phytotoxicity of the herbicide, especially if the plants had adequate soil moisture or if they were treated during summer dormancy (Bovey et al. 1986a, Meyer and Bovey 1986).

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