Effect of Soil Incorporation on Selectivity, Movement, and Persistence of Herbicides in Watermelon Plantings[1]

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Abstract. A combination treatment of preemergence *O,O*-diisopropyl phosphorodithioate *S*-ester with *N*-(2-mercaptoethyl)benzenesulfonamide (bensulide) at 5 kg/ha plus postemergence *a,a,a*-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine (trifluralin) at 0.6 kg/ha gave outstanding weed control when applications were incorporated 2.5 cm in soil. The treatment controlled redroot pigweed (*Amaranthus retroflexus* L.) and barnyardgrass [*Echinochloa crusgalli* (L.) Beauv.] without reducing the yield of 'Charleston Grey' watermelon (*Citrullus vulgaris* Schrad.). High rates of application of bensulide alone reduced yields. Isopropalin (2,6-dinitro-*N,N*-dipropylcumidine) and methyl-(4-amino-benzene)sulfonyl carbamate (MB-9057) were promising, but *N*-butyl-*N*-ethyl-*a,a,a*-trifluoro-2, 6-dinitro-*p*-toluidine (benefin), 2-chloroallyl diethyldithiocarbamate (CDEC), dimethyl tetrachloroterephthalate (DCPA), and 4-(methylsulfonyl)-2, 6-dinitro-*N,N*-dipropylaniline (nitralin) were less effective. Several herbicides controlled weeds more efficiently when soil-incorporated 5.0 cm rather than 1.3 cm. Deep incorporation of preemergence applications of benefin and trifluralin reduced the yields. Oversprays of a petroleum mulch had no effect on preemergence applications of bensulide but increased soil temp, soil moisture, and crop yields.

Laboratory bioassays showed that under high temp, furrow irrigation, and low rainfall, trifluralin moved upwards in sandy clay loam and had a half-life of 1 and 3 weeks with 1.3- and 5.0-cm incorporation in soil, respectively. Persistence of trifluralin increased with rate of application and depth of incorporation. Traces of trifluralin activity were found 5 months after treatment only with the 1.1 kg/ha application soil-incorporated 5.0 cm. Field bioassays showed that whereas bensulide, benefin, and trifluralin reduced the growth of German millet [*Setaria italica* (L.) Beauv.], only bensulide reduced the growth of sorghum (*Sorghum vulgare* L.). Crop injury increased with rate of application and depth of incorporation.

Watermelons are valued at $46 million and are produced commercially on 138,000 hectares mostly in the southern United States. Over half of the yearly production is found in Florida, Texas, and Georgia (16). In the warm soils of these states, weeds grow rapidly and inhibit the growth of watermelon seedlings. Major losses in watermelons are also caused by weeds that emerge after lengthening vines prevent further cultivation. Estimates for weed control in watermelons range from $60 to $170 per hectare.

In furrow-irrigated soils, weed control was enhanced when herbicides were soil-incorporated with a power-take-off-driven (PTO) rotary tiller (3, 7). Bensulide was reported selective in watermelons when soil-incorporated just before planting (1, 4, 15, 17). Warren (17) reported that bensulide controlled annual grass weeds at 4.4 kg/ha but failed to control common broadleaf weeds below 8.8 kg/ha. Other herbicides reported for selective weed control in watermelons were DCPA (2, 18) and *N*-1-naphthylphthalamic acid (naptalam) 2, 5). Miller and Abramitis (13) reported that watermelons grew more efficiently in cool soils when herbicides were sprayed with a black petroleum mulch. Trifluralin (4, 14) and nitralin (17) selectively controlled annual weeds when herbicides were applied after the watermelon plants were established.

In 2 preliminary experiments in 1966, preemergence soil-incorporated applications of bensulide, 2-chloroallyl diethyldithiocarbamate (CDEC), and trifluralin controlled weeds selectively in watermelons grown on a loamy sand with heavy rainfall[4]. Applications of DCPA and naptalam injured the watermelon plants. The experiments indicated the need for study of postemergence weed control in watermelon.

The main objectives of the experiments reported herein were to study, 1) the growth of weeds and watermelon as affected by soil-incorporated herbicides applied at planting and at layby, 2) the movement and persistence of herbicides in irrigated soils, 3) the effect of rainfall, soil moisture, and temp on the performance of soil-incorporated herbicides, of a petroleum mulch on the activity of soil-incorporated bensulide and the growth of watermelons. Earlier research in cantaloupe (8) provided background information for the present study.

In the present study, preemergence applications of 80% 3,4-dichlorobenzyl-N-methylcarbamate 20% 2,3-dichlorobenzyl-N-methyl-carbamate (UC-22463) and postemergence

Table 1. Average soil temp at 1.3- and 5.0-cm depths during the first 4 weeks after preemergence and postemergence herbicide applications in watermelon.[z]

Date of experiment initiation	Soil		Depth (cm)	Mean temp (C)			
				Max		Min	
	Type	Cover		Pre.	Post.	Pre.	Post.
Mar. 9, 1967	Sandy Clay Loam	None	1.3	39		19	
			5.0	33		20	
Jan. 16, 1969	Loamy Fine Sand	Mulch	1.3	30		14	
			5.0	24		16	
		None	1.3	30	40	14	19
			5.0	23	30	16	17
Jan. 17, 1970	Loamy Fine Sand	Mulch	1.3	29		9	
			5.0	25		12	
		None	1.3	21	36	10	13
			5.0	20	29	9	14

[z]Temperatures (C) at 1.3 cm in soil during preemergence treatment were 36 to 43° in 1967, 27 to 30° in 1969, and 11 to 14° in 1970 and during postemergence treatment were 44 to 45° in 1969 and 30 to 34° in 1970.

[1]Received for publication August 23, 1971. The research was a cooperative project of the Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture and the Lower Rio Grande Valley Research and Extension Center at Weslaco, Tex.

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[5]Menges, R. M. 1967, 1969,, 1970. Annual Report. Plant Science Research Division, Agricultural Research Service, U. S. Department of Agriculture.

[6]The petroleum mulch was EAP-2010, a soft "paving" grade asphalt emulsified in water.

Table 2. Soil moisture in the surface 2.5 cm of sandy clay loam and loamy fine sand in the first 4 weeks after preemergence and postemergence applications of herbicides in watermelon.

Soil					Percent of field capacity[z]				
					Weeks after treatment				
Year	Type	Cover	Depth (cm)	Time of application	0[y]	1	2	3	4
1967	Sandy Clay Loam	None	0-1.3	Pre.	2[x]	7[w]	30	22[w]	32
			1.3-2.5		5	16	59	50	38
1969	Loamy Fine Sand	Mulch	0-1.3	Pre.	56	100	2	40[w]	160
			1.3-2.5		76	61	20	80	160
		None	0-1.3		51	40	6	8[w]	160
			1.3-2.5		80	40	14	40	160
			0-1.3	Post.	20[w]	14[w]	10	14[w]	18
			1.3-2.5		80	52	18	16	24
1970	Loamy Fine Sand	Mulch	0-1.3	Pre.	210[w]	180[w]	120[w]	100	60[w]
			1.3-2.5		230	200	160	140	100
		None	0-1.3		220[w]	280[w]	40[w]	8	60[w]
			1.3-2.5		240	260	180	100	80
			0-1.3	Post.	16	12	13	11	15[w]
			1.3-2.5		20	10	16	19	21

[z]Field capacity was 19% and 5% for Hidalgo sandy loam and Delfina loamy fine sand, respectively. Data were recorded 1 day each week; large figures were rounded off.

[y]At treatment.

[x]Furrow-irrigated just after recording.

[w]Rain fell after recording; sprinkler irrigation included in 1970 postemergence data.

applications of monosodium methanearsonate (MSMA) caused excessive injury in watermelon and preemergence applications of 1-(2-methylcyclohexyl)-3-phenylurea (siduron) failed to control grass weeds. In 1968, soil-incorporated applications of bensulide, DCPA, and nitralin had no effect on emergent watermelon but trifluralin reduced the yield. Data on these herbicides are not included in the present report[5], but suggested the study of combinations of herbicides where preemergence applications are sprayed over the row at planting and postemergence applications are sprayed on the shoulders of beds at layby to avoid herbicide contact with emergent watermelon seedlings.

Materials and Methods

Three field experiments were conducted in the Lower Rio Grande Valley of Texas on Hidalgo sandy clay loam in 1967 and on Delfina loamy fine sand in 1969 and 1970. The Hidalgo sandy clay loam consisted of 75% sand, 16% clay, and 9% silt; 0.8% organic matter(hereinafter referred to as O.M.), a pH of 8.1, 19% water at field capacity and was calcareous. The Delfina loamy fine sand consisted of 89% sand, 8% clay, and 3% silt; 0.7% O.M., a pH of 6.0, and 5% water at field capacity. The soil was disked and then listed into beds and furrows. Beds were 200 cm wide with 50-cm plateaus. Herbicides were sprayed preemergence in 560 l/ha of water on the plateaus of beds and were incorporated with soil just before or after 'Charleston Grey' watermelon (*Citrullus vulgaris* Schrad.) seed were sown 1.9 cm deep in 1 row per bed. Herbicides were soil-incorporated 1.3 or 5.0 cm deep with a PTO-rotary tiller in 1967 and 2.5 cm deep with a steel mesh wheel in 1969 and 1970. The relative efficiency of the incorporation tools was recently reported (11). Efficiency levels were determined by fluorescent tracer studies (9). Herbicides were also sprayed in 51-cm bands on the shoulders of beds at layby. Treatments were replicated 4 times in a split-plot or randomized block design. Each plot consisted of 1 bed, 12.2 m long.

Redroot pigweed and barnyardgrass or German millet were seeded 1.3- to 1.9-cm deep in soil just after treatment. Weed

Table 3. Weed control and yield in watermelon with preemergence soil-incorporated herbicides. 1967.

		Percent weed control					
		Redroot pigweed		Barnyardgrass		Total yield[z] (% of weeded check)	
Herbicide	Rate (kg/ha)	1.3 cm	5.0 cm	1.3 cm	5.0 cm	1.3 cm	5.0 cm
Bensulide	4.4	75	94	65	97	80	78
	8.8	87	99	81	99	83	78
Benefin	0.8	84	98	92	98	87	81
	1.7	88	98	93	97	78	65*
Trifluralin	0.6	83	98	80	98	99	73*
	1.1	96	100	95	100	88	0*
None, weeded check		17	37	26	35		
None, non-weeded check		13	14	16	16	85	80
LSD, 5%		6		9		25	

[z]The avg yield of watermelon was 89 and 92 kg/plot in 1.3- and 5.0-cm incorporated check plots, respectively.
*Yield was significantly different from weeded check, 5% level.

control was determined 3 to 5 weeks after treatment by visual ratings (0 = no control, 100 = complete control).

Soil temp were recorded continuously for 4 to 12 weeks in the surface 5.0 cm with expansive-liquid thermographs having 0.6-cm recording probes (Table 1). Soil moisture data were recorded gravimetrically for 12 weeks in the surface 5.0 cm of soil (Table 2); rainfall was recorded weekly (Fig. 1).

Bioassays were conducted in the field and laboratory to study the movement and persistence of trifluralin in irrigated soils. Field soils untreated and treated with trifluralin in 1967 were periodically sampled 10 cm deep in 8 locations in each replicated plot. Soil samples were held less than 2 hr at 10°C in sealed field boxes and then were transferred to the laboratory and held at 25°C until bioassays were conducted. In the laboratory bioassays (9, 10) shoot growth of indicators were recorded 4 days after herbicide-treated soil was placed in Petri dishes in darkness, 25°C, 95% relative humidity. Data are reported as ppm of herbicide in soil. Bioassay indicators for trifluralin were pregerminated 'Improved Globe Y.R.' cabbage (*Brassica oleracea,* var. *capitata* L.), 'Valverde' lettuce (*Lactuca sativa,* var. *capitata* L.), 'Homestead 24' tomato (*Lycopersicon esculentum* Mill., var. *commune*), redroot pigweed and German millet.

Field bioassays were conducted in 1967 with 'RS-626' grain sorghum (*Sorghum vulgare* L.) and German millet. Beds were rotary-tilled 5.0 cm deep and planted 5 months after the preemergence herbicide applications in watermelon without loss of soil into furrows. Soil was furrow-irrigated once just after planting. Fresh wt (g) were recorded 1 month after planting.

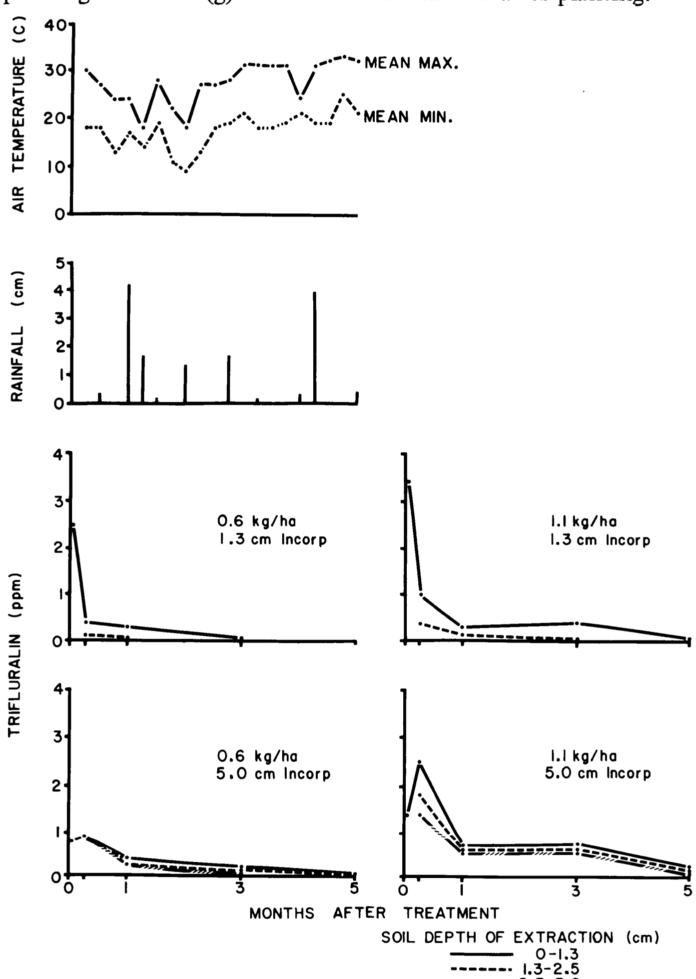

Fig. 1. Ambient temp, rainfall, and the movement and persistence of trifluralin in sandy clay loam during the first 5 months after 1967 treatments, as shown by laboratory bioassays. No herbicide activity was found below 5.0 cm in soil.

In 1969 and 1970, preemergence soil-incorporated bensulide applications were oversprayed with 6000 l/ha of petroleum mulch to study the effects of the mulch on the growth of weeds and watermelon and on the performance of the herbicide[6]. The mulch was sprayed in 20-cm bands over the row areas in 1969 and in 23-cm squares spaced 0.6 m apart in the row areas in 1970.

Results and Discussion

The growth of weeds and watermelon as affected by soil-incorporated herbicides.

Preemergence herbicide applications. In 1967, on a sandy clay loam, herbicides controlled weeds more effectively when incorporated 5.0 cm rather than 1.3 cm deep in soil (Table 3). Benefin and trifluralin, however, decreased the yield of watermelon when soil-incorporated 5.0 cm deep.

Bensulide controlled weeds at 4.4 kg/ha in 1967 and did not significantly reduce yield when soil-incorporated 5.0 cm at 8.8 kg/ha. In 1969 on a loamy fine sand, the herbicide failed to control redroot pigweed at 3.3 kg/ha but controlled it without yield reduction of watermelon at 6.6 kg/ha when incorporated 2.5 cm deep in soil (Table 4). The fact that 5 kg/ha of bensulide tended to reduce yields when soil-incorporated 5.0 cm indicates that the herbicide should be shallowly incorporated in sand to avoid injury to watermelon. Bensulide controlled annual weeds selectively in cantaloupes regardless of depth of incorporation in furrow-irrigated sandy clay loam (8). In the present study, bensulide controlled redroot pigweed and German millet efficiently in 1970 when soil-incorporated 2.5 cm at 4.4 kg/ha and had no effect on yield of watermelon even at 6.6 kg/ha in loamy fine sand (Table 5). On the basis of these and similar experiments, Texas A&M University recommends soil incorporation (2.5 cm) of bensulide 3.3 to 6.6 kg/ha with watermelon planted 2.5 cm deep in soil. In the laboratory, watermelon seedlings have tolerated soil concn of bensulide which far exceed those used in field applications (10).

The commercial use of bensulide, DCPA, and trifluralin has already begun to cause an ecological shift in weed species in vegetable fields of the southwestern USA. Summer annuals, including redroot pigweed and junglerice [*Echinochloa colonum* (L.) Link], which are readily controlled by the commercial herbicides are being replaced by resistant water annuals including London rocket (*Sisymbrium irio* L.) and ridgeseed euphorbia (*Euphorbia glyptasperma* Engelm.). Consequently, there is a critical need for new herbicides or non-chemical method which will control these new weed pests.

In 1970, 2,3-dinitro-*N,N*-dipropylcumidine (isopropalin), methyl-(4-aminobenzene)sulfonyl carbamate (MG 9057), and nitralin controlled weeds selectively and should be studied more extensively in watermelon. Perhaps one of these herbicides could be combined with bensulide to control additional weed species and to reduce residues of bensulide in soils where a rotation includes a bensulide-sensitive crop. Soil residues of bensulide from spring-treated cucurbits have been successfully used by southwestern USA growers, however, to reduce the application rates of bensulide required to control weeds in fall-planted vegetables including bensulide-tolerant lettuce, cabbage, and tomatoes.

Preemergence + postemergence herbicide applications. The outstanding combination treatment was preemergence application of bensulide in row areas + postemergence application of trifluralin in bed shoulders (Tables 4 and 5). Bensulide 3.3 kg/ha + trifluralin 0.8 kg/ha or bensulide 5 or 6.6 kg/ha + trifluralin 0.6 kg/ha selectively controlled weeds, but bensulide 6.6 kg/ha + trifluralin 0.8 kg/ha reduced the yield of watermelon on loamy fine sand. The higher rate of bensulide is apparently responsible for the yield reduction. Preemergence applications of 5 kg/ha of bensulide + 2.5 cm soil-incorporated postemergence application of 0.6 kg/ha of trifluralin should be considered for future use by growers for selective weed control

Table 4. Weed control and yield in watermelon with preemergence and postemergence applications of herbicides incorporated in the surface 2.5 cm of soil. 1969.

Herbicide application				Percent weed control[z]		
Preemergence	Rate (kg/ha)	Postemergence	Rate (kg/ha)	Redroot pigweed	Barnyardgrass	Total yield[y] (% of non-weeded check)
Bensulide	3.3			65		118
	3.3 + mulch			73		133*
	3.3	Bensulide	6.6	63	49	118
	3.3	CDEC	6.6	88	70	106
	3.3	DCPA	6.6	64	72	101
	3.3	Nitralin	1.1	20	65	117
	3.3	Trifluralin	0.8	89	90	131
	5.0[x]			82		73
	6.6			87		90
	6.6 + mulch			76		117
	6.6	Bensulide	6.6	85	52	95
	6.6	CDEC	6.6	94	78	135*
	6.6	DCPA	6.6	63	80	106
	6.6	Nitralin	1.1	34	67	73
	6.6	Trifluralin	0.8	93	85	66*
None, non-weeded check				26 + 57[w]	38	
None, non-weeded check + mulch				33		125
LSD, 5%				18 + 29	16	33

[z]Ratings are reported for only postemergence applications in combination treatments.
[y]The avg yield of watermelon was 68 kg/plot in 4 replications on non-weeded check.
[x]Soil-incorporated 5.0 cm with rotary tiller.
[w]Preemergence + postemergence.
*Significantly different from the non-weeded check, 5% level.

in watermelon grown on sands. Both herbicides are registered for use in watermelon. Postemergence applications of DCPA and trifluralin-related nitralin failed to control weeds; bensulide and CDEC controlled redroot pigweed but failed to control barnyardgrass.

Herbicide selectivity in vegetables must be extraordinary when herbicides are soil-incorporated because the vegetable roots often must grow through herbicide-treated soil (8, 12). Unreported data collected on the depths of watermelon and weed seeds and the depths of root tips of the seedlings in soil offer little explanation for herbicide selectivity in watermelon. Experiments have been initiated, however, under controlled environment to study possible correlations between the depth of vegetable and weed seed germination, the incorporation depth of herbicides in soil, and the growth patterns of seedlings under differential soil temp and moisture.

The effect of a petroleum mulch on the activity of preemergence soil-incorporated bensulide and the growth of watermelon.

In 1969, petroleum mulch had little effect on soil temp (Table 1) but materially increased the soil moisture content in the seed zone (Table 2) and increased the yield of watermelon (Table 4). In 1970, petroleum mulch increased the soil temp and moisture but had no effect on yield. Activity of bensulide was unaffected by the petroleum mulch in either year. The petroleum mulch may be practical in southwestern states to warm the soils and conserve moisture in winter plantings of cucurbits. The use of a herbicide is suggested to control the growth of weeds which is often increased with the application of the petroleum mulch.

The effect of rainfall, soil moisture, and temp on the performance of soil-incorporated herbicides.

A total of 2.8, 0, and 2.8 cm of rain fell in 1967; 3.8, 2.5, and 3.3 cm in 1969; and 0.8, 3.3, and 2.5 cm fell in 1970 during the first 3 months after treatment, respectively. In spite of the fact that the least rain fell during the first month in 1970, the loamy fine sand was colder and wetter after preemergence treatments compared to the same soil in 1969 or sandy clay loam in 1967 (Tables 1 and 2). Bensulide controlled redroot pigweed more efficiently in 1970 when the sand was colder and

Table 5. Weed control and yield in watermelon with preemergence and postemergence applications of herbicides incorporated in the surface 2.5 cm of soil. 1970.

Herbicide application				Percent weed control[z]		
Preemergence	Rate (kg/ha)	Postemergence	Rate (kg/ha)	Redroot pigweed	German millet	Total yield[y] (% of non-weeded check)
Bensulide	5			97	99	105
	5 + mulch			94	95	106
	5	Trifluralin	0.6	100	98	102
	5	Nitralin	1.1	46	16	105
	.6.6			97	100	109
	6.6 + mulch			97	99	100
	6.6	Trifluralin	0.6	100	99	99
	6.6	Nitralin	1.1	49	41	103
Isopropalin	1.1			99	100	98
MP 9057	3.3			87	99	99
Nitralin	1.7			94	90	96
None, non-weeded check				48 + 24[x]	13 + 8	
None, non-weeded check + mulch				42	8	106
LSD, 5%				20 + 24	6 + 8	N.S.

[z]Ratings are reported for only postemergence applications in combination treatments.
[y]The avg yield of watermelon was 204 kg/plot in 4 replications of non-weeded check.
[x]Preemergence + postemergence.

Table 6. Persistence of herbicides in a furrow-irrigated sandy clay loam in 1967 as indicated by percent growth reduction of field-grown sorghum and German millet 5 months after herbicide applications in watermelon.

Treatment		Percent growth reduction[z]			
		Sorghum		German millet	
		Depth of incorp. (cm)		Depth of incorp. (cm)	
Herbicide	Rate (kg/ha)	1.3	5.0	1.3	5.0
Bensulide	4.4	39*	50*	35*	85*
	8.8	47*	75*	96*	100*
Benefin	0.8	17	9	2	13
	1.7	8	0	12	46*
Trifluralin	0.6	23	0	0	31*
	1.1	5	0	0	100*
None, non-weeded check		28	20	22	17
LSD, 5%		33		28	

[z]Average of 5.1 kg of sorghum and 5.6 kg of German millet in non-weeded checks.
*Significantly different from the weeded check, 5% level.

wetter than in 1969. The herbicide controlled pigweed equally well in preemergence and postemergence applications in 1969 though soil temp were considerably higher after postemergence applications.

Unusual herbicide selectivity was experienced in 1970. Weeds were controlled without yield reduction though 29.4 cm of rainfall and sprinkler irrigation were accumulated within 10 weeks after postemergence treatments.

Lynd et al. (6) reported that the phytotoxicity of bensulide increased with increasing pH as well as with decreasing organic matter and clay. In the present study, the pH of the loamy fine sand increased from 6.0 to 6.5 during the 1969 experiment. The N source used in the experiment was liquid ammonia which is known to cause an acid reaction in sand. If $Ca(NO_3)_2$ had been substituted for ammonia the resultant increase in pH may have increased bensulide activity. A study of the effect of soil pH on the activity of bensulide under controlled environment may offer additional information on the selectivity of the herbicide in watermelon.

The movement and persistence of soil-incorporated herbicides in irrigated soils.

Sorghum was injured at low concn of bensulide but German millet was more tolerant in soil in laboratory studies (10). The opposite was noted with trifluralin. In 1967, in field bioassays, growth of millet was severely rediced by bensulide, benefin, and trifluralin (Table 6). Increased persistence in soil with increased rate of application and depth of incorporation of herbicides was observed. Only bensulide persisted 5 months in sufficient quantities to reduce the growth of sorghum. Even the lower rate of application and depth of incorporation of the herbicide caused injury.

Laboratory bioassay data indicated that the activity of trifluralin in air-dry soil 4 hr (0 days) after treatment was comparable to the theoretical activity (Fig. 1). Trifluralin is volatile at high soil temp. In the present instance, the soil was hot and dry (Tables 1 and 2) at treatment time and little herbicide activity was lost in the 4 hr delay in soil sampling. Differential activity 1 week after treatment partially explains increased weed control in 1967 with increased rate of application and depth of incorporation of trifluralin (Table 3). The half-life of trifluralin was approximately 1 and 3 weeks with 1.3- and 5.0-cm incorporation, respectively. Herbicidal activity was not found below the original depth of incorporation and only the 1.1 kg/ha application incorporated 5.0 cm persisted in as much as trace quantities after 5 months. High temp, light rainfall, and furrow-irrigation undoubtedly caused high vapor losses and thereby decreased the persistence of trifluralin in soils. Trifluralin was moved to the soil surface, presumably in a vapor state. Laboratory assays showed that sufficient trifluralin was present in soil 4 months after treatment to injure sorghum and millet more severely than they were injured in the field (10) (Fig. 1) (Table 6). Perhaps the roots of the field-grown plants, unlike laboratory-grown plants, rapidly grew below the herbicide zones in soil and recovered from injury. Thus experience and judgment are required to determine the precise time to evaluate herbicide effects on plants in field and laboratory assays of the kind reported herein.

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