Persistence of Dinitroaniline Herbicides and Potential for Injury to Sugarbeets*

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INTRODUCTION

Preplant applications of dinitroaniline (DNA) herbicides have been used for weed control in soybeans (*Glycine max* (L.) Merr.) and cotton (*Gossypium hirsutum* L.). Also, layby applications are used in sorghum (*Sorghum bicolor* (L.) Moench) and corn (*Zea mays* L.). They are broad spectrum herbicides which control most grasses and many broadleaf weeds (7). Many reports show that DNA's dissipate to a nonphytotoxic level in one growing season (2, 6, 9), while others give evidence of persistence for much longer periods (3, 10). Some factors involved in DNA persistence are photodecomposition, volatilization, adsorption to clay and organic matter, leaching, runoff, tillage, biodegradation, soil temperature, and soil moisture (6, 10, 11, 14, 15, 17). Periodic flooding and even windy conditions following application appear to affect persistence (1, 13). Differences in molecular structure of DNA's also affect persistence and phytotoxicity (5, 8). In recent years, growers have reported injury to sugarbeets (*Beta vulgaris* L.) when DNA's were used for weed control in soybean, cotton, sorghum, or corn that preceded sugarbeets in rotations. DNA's have been known to cause injury to crops including sugarbeets (1, 4, 5, 6, 10, 12, 16). Abernathy and Keeling (1) showed that DNA residues remaining after a cotton crop could be high enough to injure wheat (*Triticum aestivum* L. em Thell.) or sorghum, and to control pigweed (*Amaranthus* spp.) during the second season.

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The purpose of these studies was to determine if trifluralin, fluchloralin, profluralin, and pendimethalin used preplant incorporated (PPI) before or at layby in a previous crop will injure sugarbeets and how residues of these herbicides interact with PPI sugarbeet herbicides to cause injury.

MATERIALS AND METHODS

There were two types of experiments. In one, known amounts of herbicides were applied just prior to planting sugarbeets; in the second, DNA's were applied PPI or at layby to 'Clark 63' soybeans the year prior to planting sugarbeets. Both studies were done on Pullman clay loam (Torrertic Paleustolls; fine, mixed, thermic) consisting of 23, 46, and 31% of sand, silt, and clay, respectively, with a pH of 7.4 and 1.5% organic matter. The sugarbeet varieties were 'HH23', 'D2', and 'Tx9', respectively, in experiments conducted in 1980, 1981, and 1982.

In the first study, trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine], pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], and profluralin [N-(cyclopropylmethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl)benzenamine] were sprayed in 216 L/ha of water carrier at 0.07, 0.14, and 0.28 kg/ha each; fluchloralin [N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl)benzenamine] was applied at 0.14 kg/ha only. It was surmised that these rates would be similar to the amounts of herbicide that would persist in the soil from 6 to 12 months. In addition, DNA herbicides were overlaid with either 3.3 kg/ha ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] or 4.5 kg/ha cycloate [S-ethyl cyclohexylethylcarbamothioate], PPI sugarbeet herbicides, in a split plot design, to determine possible interactions of DNA's with regular sugarbeet herbicides. The DNA herbicides and a check were main plots and were sprayed on three 0.75-m rows that were 7.5-m long. Then the two sugarbeet herbicides or nothing were each overlaid in one of the three rows as sub-plots. After spray application, the herbicides were all incor-

porated with a rolling cultivator which mixed them into the top 4 to 6 cm of soil. Treatments were replicated three times. Sugarbeets were planted in dry soil and furrow irrigated the same or following day for emergence. These plots were rated for sugarbeet injury about 4 to 6 weeks after planting. The percent injury score reflected general condition of the crop considering both stand and vigor reduction Separate estimates of stand and vigor were not made.

In the second study, which was started in 1981 and repeated in 1982, trifluralin at 0.8 kg/ha, profluralin and fluchloralin at 1.1 kg/ha, and pendimethalin at 1.1 and 1.7 kg/ha were sprayed broadcast on beds spaced 75 cm apart and then incorporated with a rolling cultivator about 2 weeks before planting soybeans in late May. In mid-July, the same herbicides were sprayed broadcast at layby on soybeans and incorporated into the beds with a rolling cultivator to simulate use in corn and sorghum. These studies were established on level borders and the soybeans received a preplant irrigation, rainfall, and four additional irrigations during the summer. There was a total of 50 cm of irrigation water applied each year. The soybean studies were randomized blocks with four replications. The season following soybeans, sugarbeets were planted on beds maintained from the soybeans and irrigated twice for emergence before visually estimating injury. Each year, soil samples from the surface 7.5 cm were taken at 3 different dates before planting sugarbeets. Samples were taken at five locations in each plot with a spade and combined. The soil samples were quantitatively analyzed for DNA's with an Antek 300 gas chromatograph using 3% silicone OV-101 on chromosorb W-HP 80/100 mesh packing material. Differences in all studies were determined with analysis of variance and Duncan Multiple Range Tests using a 5% level of significance.

RESULTS AND DISCUSSION

In the 1980 toxicity study, pendimethalin at 0.28 kg/ha caused the most injury, 26%, to sugarbeet (Table 1).

Table 1. Sugarbeet injury in 1980 from low rates of DNA and sugarbeet herbicides.

DNA Herbicide	Application rate	DNA alone	DNA Plus Ethofumesate 3.3 kg/ha	DNA Plus Cycloate 4.5 kg/ha	Average[a]
	(kg/ha)	(% Injury)			
Trifluralin	0.07	0	3	8	3 d
	0.14	7	10	15	11 d
	0.28	13	53	28	32 b
Pendimethalin	0.07	0	7	1	3 d
	0.14	7	38	42	29 bc
	0.28	26	60	60	49 a
Profluralin	0.07	3	5	2	3 d
	0.14	7	17	13	12 cd
	0.28	10	23	10	14 bcd
Fluchloralin	0.14	3	8	7	6 d
Check		0	0	0	0 d
Average[a]		7 B	20 A	17 A	

[a]Averages followed by the same letter of the same case are not different at P 0.05 according to the Duncan's Multiple Range Test.

When the DNA herbicides were overlaid and mixed with ethofumesate and cycloate, average injury to sugarbeets increased significantly. Highest injury, 60%, occurred when pendimethalin at 0.28 kg/ha was mixed with either ethofumesate or cycloate. Injury was still high, about 40%, when pendimethalin at 0.14 kg/ha was mixed with either sugarbeet herbicide. Trifluralin at 0.28 kg/ha mixed with ethofumesate caused 53% injury. Profluralin and fluchloralin either alone or mixed with the sugarbeet herbicides were less toxic. On the average, none of the 0.07 kg/ha treatments caused significant injury to the sugarbeets.

In 1981, there was very little injury when sugarbeets were planted directly into soil treated with a DNA herbicide alone or combinations of DNA herbicides with either ethofumesate or cycloate (Table 2). There was slightly more injury to sugarbeets from trifluralin and pendimethalin than profluralin and fluchloralin. Results in

Table 2. Sugarbeet injury in 1981 from low rates of DNA and sugarbeet herbicides.

DNA Herbicide	Application rate	DNA alone	DNA Plus Ethofumesate 3.3 kg/ha	DNA Plus Cycloate 4.5 kg/ha	Average[a]
	(kg/ha)		(% Injury)		
Trifluralin	0.07	5	5	5	5 abc
	0.14	5	10	10	8 ab
	0.28	7	7	10	8 ab
Pendimethalin	0.07	5	12	12	9 a
	0.14	0	5	5	3 abc
	0.28	10	10	10	10 a
Profluralin	0.07	3	3	3	3 abc
	0.14	0	0	0	0 c
	0.28	0	0	0	0 c
Fluchloralin	0.14	0	0	5	2 bc
Check		0	0	0	0 c
Average[a]		3 A	5 A	5 A	

[a]Averages followed by the same letter of the same case are not different at P 0.05 according to the Duncan's Multiple Range Test.

1982 were similar to 1981, with trifluralin and pendimethalin causing the most injury. However, differences were not significant (Table 3). The general level of injury in 1982 may have been reduced when the sugarbeets had to be replanted 1 month after herbicide application because a hard rain crusted the soil. It is not known if variety differences played a part in the differences from year to year.

In the second type of study, two field experiments were started in 1981 and 1982. In each case, DNA's were applied to soybeans PPI or at layby. Soil samples were taken to assay DNA residues three times prior to planting sugarbeets the next year in early April. In 1981, DNA residues in the soil ranged from 0.15 to 0.41 ppm in August for PPI applications (Table 4). For layby applications in July, the range was from 0.22 to 0.78 ppm. By October, the residue resulting from all PPI applications had dropped to 0.13 ppm or less. For layby treatments, resi-

Table 3. Sugarbeet injury in 1982 following application and incorporation of DNA and sugarbeet herbicides.

DNA Herbicide	Application rate	DNA alone	DNA Plus Ethofumesate 3.3 kg/ha	DNA Plus Cycloate 4.5 kg/ha	Average[a]
	(kg/ha)	(% Injury)			
Trifluralin	0.07	19	8	10	12 a
	0.14	19	4	21	15 a
	0.28	15	0	31	15 a
Pendimethalin	0.07	0	0	28	9 a
	0.14	0	0	10	3 a
	0.28	19	0	24	14 a
Fluchloralin	0.07	0	0	0	0 a
	0.14	0	0	7	2 a
	0.28	0	8	17	8 a
Profluralin	0.14	0	0	17	6 a
Check		0	0	0	0 a
Average[a]		6 A	2 A	15 A	

[a]Averages followed by the same letter of the same case are not different at P 0.05 according to the Duncan's Multiple Range Test.

dues in August and October were higher than the PPI applications. By February, residues in the soil had dropped to 0.08 ppm or less with the exception of where 1.7 kg/ha of pendimethalin had been applied at layby.

A total of 9.7 cm of rainfall in the second week of August, 1981, occurred shortly after a late summer irrigation and flooded the level borders for 3 days. The anaerobic conditions probably caused rapid breakdown of the DNA herbicides (13). Sugarbeets planted in March of 1982 were not significantly injured by herbicide residues in the soil (Table 4).

In the 1982 experiment, flooding did not occur and herbicide residues in the soil did not decrease as much from August to March as in 1981 (Table 5). The exceptions were for the PPI applications of trifluralin, fluchloralin and the 1.1 kg/ha rate of pendimethalin. Herbicide residues with layby applications with trifluralin and profluralin did not decrease much from August to

Table 4. DNA residues in the top 7.5 cm of soil following application and incorporation of preplant and layby treatments to soybeans in 1981 along with injury to a 1982 crop of sugarbeets.

Herbicides	Application rate	Treatment time	Residue in soil[a] 1 Aug. 1981	15 Oct. 1981	18 Feb. 1982	Sugarbeet injury in 1982 [b]
	(kg/ha)		(ppm)			(%)
Trifluralin	0.8	PPI	0.15 fgh	0.04 h	0.08 gh	13 a
		Layby	0.22 ef	0.10 gh	0.06 h	20 a
Profluralin	1.1	PPI	0.23 ef	0.11 fgh	0.02 h	15 a
		Layby	0.43 cd	0.10 gh	0.01 h	20 a
Fluchloralin	1.1	PPI	0.34 de	0.07 h	0.01 h	0 a
		Layby	0.52 bc	0.19 fg	0.05 h	10 a
Pendimethalin	1.1	PPI	0.19 fg	0.06 h	0.02 h	12 a
		Layby	0.78 a	0.15 fgh	0.05 h	5 a
Pendimethalin	1.7	PPI	0.41 cd	0.13 fgh	0.06 h	18 a
		Layby	0.54 b	0.23 ef	0.16 fgh	29 a
Check			0.00 h	0.00 h	0.00 h	0 a

[a]Residues in the soil (any date, rate, or herbicide) with the same letter are not different according to Duncan's Multiple Range Test at P 0.05.

[b]Injury is not significantly different from the check according to Duncan's Multiple Range Test at P 0.05.

Table 5. DNA residues in the top 7.5 cm of soil following application and incorporation of preplant and layby treatments to soybeans in 1982 along with injury to a 1983 crop of sugarbeets.

Herbicides	Application rate	Treatment time	Residue in soil[a] 20 Aug. 1982	15 Oct. 1982	15 Mar. 1983	Sugarbeet injury in 1983 [b]
	(kg/ha)		(ppm)			(%)
Trifluralin	0.8	PPI	0.36 cd	0.22 e-i	0.14 h-k	6 e
		Layby	0.40 abc	0.36 cd	0.32 cde	14 de
Profluralin	1.1	PPI	0.30 c-f	0.30 c-f	0.32 cde	21 de
		Layby	0.49 ab	0.41 abc	0.50 a	41 bcd
Fluchloralin	1.1	PPI	0.16 h-k	0.15 h-k	0.10 ijk	11 de
		Layby	0.26 d-h	0.30 c-f	0.19 f-j	41 bcd
Pendimethalin	1.1	PPI	0.15 h-k	0.16 g-j	0.09 ijk	25 ce
		Layby	0.26 d-h	0.28c-g	0.14 h-k	55 abc
Pendimethalin	1.7	PPI	0.22 e-i	0.25 e-h	0.21 e-i	58 ab
		Layby	0.39 abc	0.37 bcd	0.24 e-h	75 a
Check			0.00 k	0.00 k	0.00 k	0 e

[a]Residues in the soil (any date, rate, or herbicide) with the same letter are not different according to Duncan's Multiple Range Test at P 0.05.

[b]Injury is not significantly different from the check according to Duncan's Multiple Range Test at P 0.05.

March. About 50% decrease occurred with fluchloralin and pendimethalin. The following spring, sugarbeet injury was as high as 75% with 1.7 kg/ha pendimethalin applied at layby (Table 5). With the exception of pendimethalin at 1.7 kg/ha, none of the PPI treatments caused significant injury. Trifluralin at 0.8 kg/ha was the only layby

treatment that did not cause injury to the sugarbeets.

Toxicity studies showed that trifluralin and pendimethalin at 0.28 kg/ha have the potential for seriously injuring sugarbeets. When the soil has this level or more of the two herbicides, sugarbeets should not be planted. Assuming that the top 7.5 cm of a ha of soil weighs about 1 million kg, a 1.0 kg/ha rate of herbicide incorporated into the top 7.5 cm equals 1.0 ppm. In 1983, residues in the soil following layby application to soybeans in 1982, ranged from 0.14 to 0.50 ppm. This caused similar or more toxicity to the subsequent sugarbeet crop than occurred in the toxicity studies where the top rate of application was 0.28 kg/ha.

These studies indicate that PPI applications of trifluralin and pendimethalin at normal rates of 1 kg/ha or less to a previous crop are not likely to injure sugarbeets the following year. Layby applications applied to corn or sorghum are likely to cause injury. Also, ethofumesate and cycloate applied preplant on sugarbeets increase the potential for injury from DNA herbicides used the previous year.

SUMMARY

The injury to sugarbeets caused by trifluralin, pendimethalin, fluchloralin, and porofluralin applied immediately before planting sugarbeets or when applied preplant incorporated (PPI) or incorporated at layby for soybeans grown prior to sugarbeets was determined on clay loam soil. In 3 years of toxicity studies, the herbicides were applied and incorporated at 0.07, 0.14, and 0.28 kg/ha immediately before planting sugarbeets. Then, either no herbicide, ethofumesate at 3.3 kg/ha, or cycloate at 4.5 kg/ha were mixed with the DNA herbicides. In another 2 year study, the DNA herbicides were applied at from 0.8 to 1.7 kg/ha, either PPI or layby in soybeans. The toxicity studies showed that pendimethalin and trifluralin were more toxic to sugarbeets than profluralin or fluchloralin. When ethofumesate and cycloate were added to the DNA's, toxicity increased. Studies showed that PPI

applications of trifluralin or pendimethalin to a rotational crop 12 months before planting sugarbeets may or may not injure the sugarbeets. The chance for injury decreased when soil was flooded by a combination of irrigation and rain. Layby treatments of trifluralin or pendimethalin to rotational crops about 8 months prior to planting sugarbeets are likely to cause injury.

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