Dinitroaniline Herbicide Carry Over to Sugarbeet[†]

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ABSTRACT

A four-year field experiment was conducted near Scottsbluff, NE to compare degradation of ethalfluralin, pendimethalin, and trifluralin in soil. Dinitroaniline herbicides were applied at rates of 0.56, 1.12, and 2.24 kg/ha preplant incorporated before planting dry edible bean. Herbicide degradation was monitored by chemical extraction and gas chromatography. Sugarbeet followed dry edible bean in the crop rotation and crop growth was related to dinitroaniline herbicide concentrations in soil. Moldboard plowing of the soil before sugarbeet planting reduced dinitroaniline herbicide concentration in the upper 0 to 8 cm of the soil profile by 39 and 76% in 1990 and 1992, respectively. Plowing increased the concentration of herbicide in the 15 to 30 cm zone of the soil profile. Ethalfluralin degraded more rapidly than pendimethalin or trifluralin. Eleven months after herbicide application, residues of 0.07 mg/kg or greater of pendimethalin or trifluralin in the upper 0 to 8 cm of the profile reduced sugarbeet growth and stand.

Additional Key Words: Ethalfluralin, pendimethalin, trifluralin.

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The dinitroaniline family of herbicides has been used extensively to control weeds in cotton (*Gossypium* spp.), soybean [*Glycine max* (L.) Merr.], and minor crops such as dry edible bean (*Phaseolus vulgaris* L.). These herbicides are normally applied to the soil surface and mechanically incorporated to depths of 2 to 8 cm. Several experiments have demonstrated that dinitroaniline herbicides can persist in the soil and carry over to affect succeeding crops (Abernathy and Keeling, 1979; Jacques and Harvey, 1979; Warner, et al. 1987). Trifluralin applied at 1.3 or 2.2 kg/ha carried over to the following season and injured sorghum [*Sorghum bicolor* (L.) Moench] or corn (*Zea mays* L.), respectively (Burnside, 1974; Abernathy and Keeling, 1979; Hartzler, et al., 1989). In similar studies, trifluralin and pendimethalin were found to have the potential to carry over and injure sugarbeet (*Beta vulgaris* L.) (Warner, et al., 1987). The carry over potential of trifluralin was reduced when soils were plowed before planting succeeding crops (Fink, 1972; Burnside, 1974; Hartzler, et al. 1989). Soil concentrations of trifluralin at the 0 to 7.5 cm depth were reduced 62% by moldboard plowing, with subsequent reduction in corn injury (Hartzler, et al. 1989).

Rates of soil degradation differ among the dinitroaniline herbicides. Benefin had a half life of 5.7 months, while trifluralin had a half life of 12.5 months in a sandy loam soil (Zimdahl and Gwynn, 1977). Trifluralin was lost more rapidly than pendimethalin when not mechanically incorporated into soil (Savage and Jordan, 1980). When exposed to solar radiation there was more photodecomposition of trifluralin than pendimethalin (Parachetti and Dec, 1978). Environmental parameters such as soil type, soil moisture, and temperature also influence dinitroaniline degradation. Trifluralin dissipated more rapidly in a sandy loam soil than in a loam (Zimdahl, et al., 1984). Dinitroaniline herbicides also have been shown to dissipate more rapidly in soil at higher water contents (Jacques and Harvey, 1979). As soil temperatures increased from 10 to 30 C pendimethalin degradation increased (Zimdahl, et al. 1984).

Several studies have shown that trifluralin as well as other members of the dinitroaniline herbicide family are not generally susceptible to leaching when applied to the soil (Menges and Tamez, 1974; Miller, et al., 1978). Trifluralin remained within the original soil zones of incorporation 6 months after application.

Ethalfluralin, pendimethalin, and trifluralin are commonly used for weed control in dry edible bean. In many of the sugarbeet growing regions of the United States, sugarbeet may follow dry edible bean in the crop rotation. Thus, the potential exists for herbicide carry over to injure sugarbeet. The objectives of these studies were to: a) determine the effect of residual ethalfluralin, pendimethalin, and trifluralin on sugarbeet, b) compare degradation of these herbicides in soil under field conditions, and c) determine the effect of preplant moldboard plowing on herbicide concentration and toxicity to sugarbeet.

MATERIALS AND METHODS

Field experiments were conducted near Scottsbluff, Nebraska, in 1989 to 1990 on a Tripp sandy loam (Typic Haplustoll), pH 7.6 and 1.3% organic matter. The experiment was repeated in 1991 to 1992 on a Tripp very fine sandy loam with a pH 7.5 and 1.1% organic matter. Experimental design was a split plot with ten main plots (three herbicides at three rates and an untreated control) and two subplots (moldboard plowed or not plowed). All treatments were replicated three times. Subplots were 4.5 m wide by 9.1 m long.

Ethalfluralin, pendimethalin, and trifluralin were each applied at 0.56, 1.12, and 2.24 kg ai/ha, and immediately incorporated with a power driven rototiller operated at a depth of 5 to 8 cm. The herbicides were applied broadcast in water at 200 L/ha with a tractor-mounted sprayer on June 7, 1989 or June 5, 1991. Dry edible bean was planted one day following herbicide application. Dry edible bean was grown in a conventional manner, irrigated with an overhead sprinkler in 1989 and by furrow in 1991. The bean crop was harvested in mid-September in both 1989 and 1991.

In the spring of 1990 and 1992, all plots were disced and then half of each main plot was moldboard plowed to a depth of 20 cm. The entire plot area was then roller harrowed twice to level and firm the soil. Sugarbeet 'Hilleshog Mono-Hy 1605' was planted 2.5cm deep on April 19 in both 1990 and 1992. Sugarbeet was grown in a conventional manner, irrigated with an overhead sprinkler in 1990 and by furrow in 1992. All plots were kept weed free by handweeding and cultivation.

Visual estimates of early season sugarbeet injury (0 = no injury and 100 = completely killed) were recorded in mid-May and early June. Sugarbeet stand was determined by counting plants in 7.6 m of crop row. Stand counts were taken in mid-June. Sugarbeet was topped, harvested, and weighed by hand during early October. A 9- kg subsample from each plot was washed, weighed, and analyzed for sucrose content by the method outlined by the Association of Official Agriculture Chemists (1955).

An analysis of variance (ANOVA) indicated significant year by main plot and subplot interactions; therefore, data for each two year period were analyzed separately. Sugarbeet response to herbicide treatments and the untreated check were analyzed for plowed and not plowed subplots. Mean separation was performed using Fisher's Protected Least Significant Difference (LSD) at the 0.05 level of significance. Dinitroaniline herbicide dissipation data were subjected to a repeated-measures multivariate analysis and split plot analysis, and treatments were compared by single degree of freedom orthogonal contrasts.

Residue analysis. In 1989 and 1990, subplots were sampled 138, 331, and 505 days after dinitroaniline herbicide application. Subplots were sampled 6, 113, 341, and 504 days after herbicide application in 1991 and 1992. Ten soil cores were taken with a 5 cm diameter soil probe to a depth of 0 to 8, 8 to 15, and 15 to 30 cm from each subplot. Soil cores from each subplot were combined, mixed, and frozen at -15C.

After thawing, soil samples were pulverized, mixed within the bag, and 48 g (moist as received) was placed into 250 ml polypropylene bottles. Methanol (100 ml) was added and the sample was shaken on a gyrotory shaker for 1 h. Soil was separated from the extract with a 9 cm Buchner suction funnel and Whatman #1 filter paper. The extract was poured into a 250 ml separatory funnel, 120 ml of aqueous saline solution (2% NaCl, w/v) and 40 ml of carbon tetrachloride (pendimethalin) or dichloromethane (trifluralin and ethalfluralin) were added. After 1.5 min of shaking, the phases were allowed to separate, and the extract was drained into a 125 ml flask. The extraction was repeated with 40 ml additional carbon tetrachloride (pendimethalin) or dichloromethane (trifluralin and ethalfluralin) and the extracts were combined. After addition of 30 μl of 1-octanol (pendimethalin) or 2 ml of xylene (trifluralin and ethalfluralin) as a stabilizer, the carbon tetrachloride (pendimethalin) or dichloromethane (trifluralin and ethalfluralin) was removed by vacuum rotary evaporation in a water bath at 38 C. With trifluralin and ethalfluralin, dichloromethane removal was considered complete by the loss of 0.2 to 0.3 ml of the original volume of xylene. In the pendimethalin analysis the sample residue was dissolved in 1.7 to 2.0 ml of xylene for analysis by gas-liquid chromatography.

The gas chromatograph was a Hewlett-Packard 5840 with a nitrogen-phosphorus specific thermionic detector and dedicated microprocessor. The separation column for pendimethalin was a 91 cm x 2 mm I.D. glass packed with 1.5% SP2250 + 1.95% 2401 on 100/120 mesh Supelcoport. The inlet port temperature was 205 C; column oven and detector temperatures were 191 C and 300 C, respectively. Nitrogen carrier gas flow was 19.2 cc/min; respective flow rates for detector air and hydrogen were 50 and 3 cc/min. The separation column for trifluralin and ethalfluralin was a 122 cm x

2 mm I.D. glass column packed with 3% ov 25 on 100/120 mesh Chromosorb W HP. Column oven temperature was 161 C. All other operating variables were as described for pendimethalin analysis. Quantification of herbicide was by the external standard method. Herbicide recovery from 48 g soil spiked with pendimethalin or trifluralin was 97%; ethalfluralin recovery was 92%.

RESULTS AND DISCUSSION

Herbicide carry over and sugarbeet injury. Less dinitroaniline herbicide residue was detected in soil and less sugarbeet injury was observed during 1991/1992 than 1989/1990 (Tables 1, 2, and 3). Air temperatures during the respective study periods averaged 9 and 9.8 C while rainfall for the same periods was 28.8 and 24.9 cm. Soils at the two experimental sites were similar in texture, organic matter content, and pH. The major difference between the two locations was how the dry edible bean and sugarbeet crops were irrigated. During the 1989/1990 growing season dry edible bean and sugarbeet were irrigated with an overhead sprinkler system, while in 1991/1992 the crops were ditched and furrow irrigated. The plot area was also located at the upper end of the field near the irrigation water source. In 1991/1992 ditching moved soil into the crop row, plus furrow irrigation applied more water to the crop, at the upper end of the field, and soil consequently had a higher moisture content through much of the growing season. Previous research has shown that dinitroaniline herbicides dissipate more rapidly in wet soil than in dry soil (Jacques and Harvey, 1979). Pendimethalin and trifluralin carry over to sugarbeet was reduced when soils were flooded due to abnormal rainfall (Warner, et al., 1987). Higher soil water content during the 1991/1992 growing season due to plot location and furrow irrigation probably enhanced degradation, reducing injury to sugarbeet from carry over.

Ethalfluralin concentration was lower in soil than pendimethalin and trifluralin while concentrations of the latter herbicides were similar in both years (Table 1). Dinitroaniline concentrations were lowest when herbicides were applied at 0.56 kg/ha and highest when applied at 2.24 kg/ha. Dinitroaniline concentrations were greatest when soil was sampled 138 or 113 days after application in 1989 or 1991, respectively.

Soil was sampled six days after application in 1991, to determine herbicide loss by volatilization and photodecomposition. Although herbicides were applied at the same rate and incorporated after application, pendimethalin concentrations were higher than ethalfluralin or trifluralin (data not presented). More ethalfluralin and trifluralin were probably lost due to volatilization and photodecomposition.

Table 1. Dinitroaniline herbicide dissipation in the upper 0 to 8 cm of soil in nonplowed areas following application to dry edible bean.

Contrasts	1989 to 1990		1991 to 1992	
	Average herbicide concentration 138, 331 and 505 days after application	Significance of F Value†	Average herbicide concentration 113, 341, and 504 days after application	Significance of F Value†
	mg/kg		mg/kg	
Main Plot				
Ethalfluralin vs. pendimethalin	0.037 vs. 0.136	**	0.012 vs. 0.048	**
Ethalfluralin vs. trifluralin	0.037 vs. 0.143	**	0.012 vs. 0.059	**
Pendimethalin vs. trifluralin	0.136 vs. 0.143	NS	0.048 vs. 0.059	NS
Ethalfluralin vs. pendimethalin & trifluralin	0.037 vs. 0.140	**	0.012 vs. 0.053	**
Application rate 0.56 vs. 1.12 kg/ha	0.052 vs. 0.076	NS	0.021 vs. 0.034	**
Application rate 1.12 vs. 2.24 kg/ha	0.076 vs. 0.188	**	0.034 vs. 0.064	**
Application rate 0.56 vs. 1.12 and 2.24 kg/ha	0.052 vs. 0.132	**	0.012 vs. 0.049	**
Subplots				
Date of sampling 138 vs. 331 and 505 days after application 1989 to 1990	0.187 vs. 0.065	**		
Date of sampling 113 vs. 341 and 504 days after application 1991 to 1992			0.074 vs. 0.022	**
Date of sampling 331 vs. 505 days after application 1989 to 1990	0.100 vs. 0.030	**		
Date of sampling 341 vs. 504 days after application 1991 to 1992			0.036 vs. 0.009	NS

** Significant at 0.01 level of probability; NS = not significant.

Trifluralin is photodecomposed to a greater extent than pendimethalin on the soil surface (Parochetti and Dec, 1978: Savage and Jordan, 1980). Trifluralin appeared more susceptible to loss from the upper 0 to 8 cm of soil during the first six days after application than pendimethalin. Ethalfluralin loss was intermediate to the two other herbicides. Later in the growing season pendimethalin and trifluralin concentrations were higher than ethalfluralin (Table 1). These differences can be attributed to differences in half-lives of ethalfluralin, pendimethalin, and trifluralin in soil (Weed Sci. Soc. Am., 1994).

Effect of tillage. Moldboard plowing before sugarbeet planting re duced dinitroaniline herbicide concentration at the 0 to 8 cm depth by 39% in 1990 (Table 2) and 76% in 1992 (Table 3) compared to not plowing. Herbicide was moved by the plow from surface soil to the 15 to 30 cm depth. These observations are similar to those of Hartzler, et al., (1989) who reported a 62% reduction in trifluralin concentration in the upper 0 to 7.5 cm of soil after moldboard plowing.

Sugarbeet early season vigor (indicated by visual injury and stand) was greater in plowed areas than in nonplowed areas in 1990 (Table 2). In 1992, sugarbeet root yields were higher in plowed plots than in unplowed plots (Table 3). Reduction in crop injury from plowing is the result of reducing herbicide concentration in the upper soil zone (Hartzler, et al., 1989). Dinitroaniline herbicides are absorbed by emerging shoots as they move toward the soil surface (Knake, et al., 1967). Plant roots may also absorb dinitroaniline herbicide but translocation to shoots is minimal (Negi and Funderburk, 1968). Moldboard plowing reduces dinitroaniline herbicide concentration near the soil surface and emerging sugarbeet shoots are exposed to less herbicide. Although the sugarbeet root is exposed to dinitroaniline herbicide at lower depths in the soil following plowing, the roots do not translocate sufficient quantities of the herbicide to reduce sugarbeet growth.

Ethalfluralin applied at 0.56 to 2.24 kg/ha in 1989 did not carry over and reduce sugarbeet vigor or stand in 1990 in unplowed plots (Table 2). Early season vigor was reduced by herbicide carry over from areas treated in 1989 with pendimethalin at 2.24 kg/ha and trifluralin at 0.56 or 2.24 kg/ha. Trifluralin applied at 2.24 kg/ha in 1989 carried over and reduced sugarbeet stand in 1990. In similar experiments, Warner et al. (1987) found soil concentrations of trifluralin and pendimethalin of 0.14 to 0.50 mg/kg reduced sugarbeet early season vigor. Sugarbeet root yields in 1990 were not significantly different from the untreated control; however, there was a trend toward lower root yields in plots previously treated with trifluralin at 2.24 kg/ha. Sucrose content of sugarbeet roots harvested from areas treated the previous year with pendimethalin at 2.24 kg/ha were reduced compared to the un-

Table 2. Effect of dinitroaniline herbicides applied in 1989 on sugarbeet planted in 1990.

Herbicide applied to dry beans 6/7/89	Rate	Tillage method before planting sugarbeet in 1990	Herbicide concentration 331 days after application (5/3/90) in the upper 0 to 8 cm of soil	Sugarbeet: Visual injury 5/21/90	Sugarbeet: Stand 6/11/90	Sugarbeet: Root yield	Sugarbeet: Percent sucrose
	kg/ha		ppmw	%	plants/7.6 m of row	kg/ha	%
Ethalfluralin	0.56	Roller harrow	0.0095	0	152	74600	16.8
	1.12		0.0378	5	169	78200	16.4
	2.24		0.0528	8	138	76200	16.7
Pendimethalin	0.56		0.0847	13	161	79000	16.1
	1.12		0.0943	28	138	73200	16.6
	2.24		0.2437	53	122	70100	14.9
Trifluralin	0.56		0.0727	40	141	70300	15.9
	1.12		0.0857	20	163	72600	16.4
	2.24		0.2180	63	108	59600	15.1
Untreated control	—		—	0	161	76400	16.2
LSD (0.05)				30	46	NS	1.1
Ethalfluralin	0.56	Plow/roller harrow	0.0131	0	183	86500	16.9
	1.12		0.0184	0	187	75700	16.5
	2.24		0.0248	5	210	75900	16.9

Table 2. Effect of dinitroaniline herbicides applied in 1989 on sugarbeet planted in 1990. *(Continued)*

Herbicide applied to dry beans 6/7/89	Rate	Tillage method before planting sugarbeet in 1990	Herbicide concentration 331 days after application (5/3/90) in the upper 0 to 8 cm of soil	Sugarbeet			
				Visual injury 5/21/90	Stand 6/11/90	Root yield	Percent sucrose
	kg/ha						
Pendimethalin	0.56		0.0603	16	223	82000	15.6
	1.12		0.0573	10	208	93400	15.4
	2.24		0.1963	30	129	76200	15.7
Trifluralin	0.56		0.0263	3	168	89600	16.0
	1.12		0 0753	3	170	72100	16.8
	2.24		0.0706	26	177	60700	16.0
Untreated control	—		—	0	156	62700	15.5
LSD (0.05)				NS	55	NS	NS
Soil depth 0 to 8 cm		Roller harrow	0.0998	23	145	73100	16.1
		Plow/roller harrow	0.0603	9	181	77500	16.1
		LSD (0.05)	0.0330	10	15	NS	NS
Soil depth 15 to 30 cm		Roller harrow	0.0069				
		Plow/roller harrow	0.0372				
		LSD (0.05)	0.0097				

Table 3. Effect of dinitroaniline herbicides applied in 1991 on sugarbeet planted in 1992.

Herbicide applied to dry beans 6/5/91	Rate	Tillage method before planting sugarbeet in 1992	Herbicide concentration 341 days after application (5/11/92) in the upper 0 to 8 cm of soil	Sugarbeet			
				Visual injury 6/17/92	Stand 6/22/92	Root yield	Percent sucrose
	kg/ha		mg/kg	%	plants/7.6 m of row	kg/ha	%
Ethalfluralin	0.56	Roller harrow	0.006	0	136	34500	18.4
	1.12		0.017	1	85	29300	18.1
	2.24		0.012	0	84	43900	18.1
Pendimethalin	0.56		0.018	0	133	38500	18.5
	1.12		0.023	0	135	39400	18.7
	2 24		0.080	5	98	35600	18.5
Trifluralin	0.56		0.040	0	118	36700	18.3
	1.12		0.051	4	106	33600	17.9
	2.24		0.076	9	106	31600	18.6
Untreated control	—		—	0	109	31800	18.3
LSD (0.05)				4	35	NS	NS
Ethalfluralin	0.56	Plow/roller harrow	0.001	0	112	50600	18.1
	1.12		0.002	3	105	44800	18.6
	2.24		0.003	5	103	39900	18.7

Table 3. Effect of dinitroaniline herbicides applied in 1991 on sugarbeet planted in 1992. *(Continued)*

Herbicide applied to dry beans 6/5/91	Rate	Tillage method before planting sugarbeet in 1992	Herbicide concentration 341 days after application (5/11/92) in the upper 0 to 8 cm of soil	Sugarbeet: Visual injury 6/17/92	Sugarbeet: Stand 6/22/92	Sugarbeet: Root yield	Sugarbeet: Percent sucrose
	kg/ha		mg/kg	%	plants/7.6 m of row	kg/ha	%
Pendimethalin	0.56		0.007	5	107	44400	18.7
	1.12		0.021	2	109	44800	19.2
	2.24		0.013	4	115	42100	18.1
Trifluralin	0.56		0.007	5	108	40300	18.5
	1.12		0.004	2	116	44600	18.6
	2.24		0.017	4	131	42800	18.7
Untreated control	—	—	—	0	113	45000	18.6
LSD (0.05)				NS	NS	NS	NS
Soil depth 0 to 8 cm		Roller harrow	0.036	3	111	35400	18.6
		Plow/roller harrow	0.008	2	112	43900	18.3
		LSD (0.05)	0.007	NS	NS	3100	NS
Soil depth 15 to 30 cm		Roller harrow	0.002				
		Plow/roller harrow	0.020				
		LSD (0.05)	0.004				

treated control.

Less sugarbeet injury observed in 1992 from dinitroaniline herbicides applied in 1991 than in the previous rotation was due to lower herbicide concentrations in the soil (Table 3). Early season sugarbeet vigor in 1992 in unplowed plots was reduced in areas treated the previous year with pendimethalin or trifluralin at 2.24 kg/ha. Sugarbeet stand and sucrose content were not affected by herbicide carry over, while root yield was greater in plowed versus unplowed plots. Experiments indicated a reduction in early season sugarbeet vigor when surface soil (0 to 8 cm depth) contained 0.07 mg/kg or more pendimethalin or trifluralin (Table 2 and 3). Moldboard plowing reduced sugarbeet injury from pendimethalin and trifluralin. In most situations sugarbeet growers can reduce the effect of ethalfluralin, pendimenthalin, and trifluralin by following the herbicide label which suggests herbicide rates for various soil types and mold board plowing before planting sugarbeet.

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