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Trifluralin Volatilization Losses from a Soybean Field[1]

A. W. White, Jr., L. A. Harper, R. A. Leonard, and J. W. Turnbull[2]

ABSTRACT

We measured trifluralin (α,α,α-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) concentrations in air and calculated volatilization losses from a 1.26-ha field during application at soybean [*Glycine max* (L.) Merr.] planting and for 120 days after. Air samples, collected at three heights above the soil on 9 days during the season, showed that distinct trifluralin air concentration gradients existed throughout the study with concentrations highest closest to the ground. The highest concentration was measured during the application period (prior to soil herbicide incorporation) when a trifluralin level of 16,500 ng/m^3 was recorded 20 cm above the ground. Generally, air concentrations were highest early in the season and decreased rapidly the first month. After herbicide incorporation, trifluralin air concentrations at 20 cm reached a maximum of 3,400 ng/m^3 on day 2, and never exceeded 100 ng/m^3 after day 35. Soil trifluralin levels at the 0.5-cm depth decreased from 1.65 to about 0.3 μg/g on day 35 and to about 0.1 μg/g after 120 days.

Seasonal trifluralin volatilization loss, excluding the application period, was estimated to be 22.4% of that applied with vapor losses during application amounting to 3.5% of the applied herbicide. Thus, total seasonal aerial losses were 25.9% of the originally applied herbicide. Of the total aerial losses, 13 and 15% were lost during application and through day 1, respectively. About half was lost during the first 9 days, and 90% in 35 days. Combined seasonal losses by other pathways (excluding volatilization) were almost 2.5 times greater than aerial losses.

Additional Index Words: pesticides, pesticide flux, aerial losses, air concentrations, vaporization, micrometeorology, degradation, soil persistence.

Volatilization and aerial transport are important processes in the dissipation of pesticides. Recent reports have indicated that for some field-applied pesticides, volatilization from plant, water, and soil surfaces can be a major pathway of loss (Spencer et al., 1973; Caro and Taylor, 1971; Willis et al., 1972).

Controlled laboratory experiments have been used extensively to study pesticide volatility and to evaluate factors affecting pesticide volatilization. Many workers have evaluated the importance of chemical and physical properties of the pesticide, as well as the influences of other factors, like temperature, airflow rate, soil moisture, and various soil properties. Mechanisms involved and interrelationships among these factors have been discussed fully in several papers (Spencer et al., 1973; Spencer and Cliath, 1975; Spencer and Cliath, 1977).

Literature reports of field studies are limited where vaporized pesticides were measured directly in the air and estimates were made of total volatilization losses. Since micrometeorological data and computational techniques to determine pesticide flux are not readily available to many pesticide researchers, workers have measured aerial pesticide concentrations above treated fields without computing total volatilization losses. Willis et al. (1969) reported that endrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-*endo-endo*-5,8-dimethanonaphthalene) atmospheric concentrations reached a maximum of 540 ng/m^3 during the 3-day period after application and then decreased to 123 ng/m^3 after 21 days. Cliath and Spencer (1972) measured DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane] air concentrations of 555 ng/m^3 during a 39-hour period after disking soil containing high residual DDT from past treatments. In another study with soil-applied DDT, Willis et al. (1971) measured aerial concentrations at 10- and 30-cm above the ground for 6 months. They reported DDT concentrations at 10 cm dropped from an initial maximum of 2,041 ng/m^3 to 100 ng/m^3 within 2 days and seldom exceeded the 2-day level thereafter.

Some investigators have estimated pesticide volatilization losses under field conditions. Caro et al. (1971) calculated seasonal volatilization losses of soil incorporated dieldrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-*endo-exo*-5,8-dimethanonaphthalene) and heptachlor (1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene) above a corn (*Zea mays* L.) field. They used meteorological data and microclimate methods (Parmele et al., 1972) to determine flux rates and found that 2.8% of the dieldrin and 3.9% of the heptachlor, applied at rates of 5.6 kg/ha, volatilized during the season. Willis et al. (1972) using an aerodynamic method for estimating dieldrin volatilization from a fallow soil at a 30-cm height found maximum concentrations of 8 to 12 μg/m^3 on day 1. They reported that soil moisture had a definite effect on dieldrin volatilization rate. Over a 5-month period, about 18% of the applied dieldrin volatilized from plots kept moist by daily sprinkling, whereas only 7% volatilized from natural rainfall plots.

Trifluralin (α,α,α-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) is used extensively as a pre-emergence soil-incorporated herbicide for controlling several grasses and broadleaf weeds. The herbicide volatilizes at significant rates from soils and, under laboratory conditions, researchers have related vaporization losses with temperature, concentration, mode of application, soil moisture, and other soil properties (Bardsley et al., 1968; Ketchersid et al., 1969; Swann and Behrens, 1972; Spencer and Cliath, 1974). Spencer and Cliath (1974) showed that at 19% soil water content, potential volatility of trifluralin was 3,000 to 5,000 times greater than that when the soil was air dry. Since trifluralin is volatile and readily degrades in the presence of ultraviolet light (Wright and Warren, 1965; Harrison and Anderson, 1970; Probst and Tepe, 1969; Parr and Smith, 1973; Leitis and Crosby, 1974), it is more effective under field conditions when it is soil incorporated (Pieczarka et al., 1962; Smith and Wiese, 1973). Trifluralin does not accumulate in soils with repeated applications and is not readily leached (Anderson et al., 1968; Parka and Tepe, 1969; Smith, 1972). It dissipates in soils to low residual levels within a growing season (Probst et al., 1967; Smith, 1972; Savage, 1973). Trifluralin chemical and physical properties and

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pathways of degradation have been discussed by Probst et al. (1967), Probst and Tepe (1969), and Parr and Smith (1973). Evidence suggests that nonbiological or physicochemical decomposition may be an important pathway for trifluralin degradation in soils (Probst and Tepe, 1969; Messersmith et al., 1971).

No previous studies on seasonal trifluralin volatilization losses have been reported. This paper reports aerial concentrations and volatilization losses of trifluralin during a 120-day period under field conditions. The effects of soil and microclimate factors on trifluralin volatilization during several selected sampling periods were reported previously (Harper et al., 1976).

MATERIALS AND METHODS

The study area was located at Watkinsville, Georgia, on a 1.26-ha experimental watershed with a slope of 3.0%. The Cecil soil (63.9% sand, 23.6% silt, and 12.5% clay) had 0.55% organic carbon and a pH of 6.5. Harper et al. (1976) presented a detailed description of the site, the equipment and installation required for collecting microclimate data, and summarized the methods, assumptions, and calculations used for determining flux rates.

Trifluralin was surface applied as a spray, using a ground sprayer equipped with flat-fan nozzles 50.8 cm (20 inches) apart and 48.3 cm (19 inches) above the soil surface, at a rate of 1.12 kg/ha between 1220 and 1247 eastern daylight time (EDT) on 15 June 1973. The sprayer was calibrated to deliver 187 liters/ha (20 gallons/acre) at 1.41 kg/cm^2 (20 pounds/inch^2) while traveling 4.8 km/hour (3 mph). After application, the herbicide was soil incorporated with a contra-rotating tine tiller and soybeans [*Glycine max* (L.) Merr] were planted. The combined operations were complete by 1337 (EDT). Experimental grade trifluralin (from Eli Lilly and Co.)[3] containing 44.5% trifluralin in emulsifiable concentrate form was used in the study.

Air samples were collected at temporary sampling stations during the application-incorporation period (1220–1337 EDT). Immediately after application, all air sampling and meteorological equipment was installed and subsequent sampling started at 1700 EDT. Air was sampled continuously throughout the remainder of day 1 (15 June 1973) and through day 2 using 4-hour sample intervals, except for the first three samples which were 3 hours each. Air samples were collected on days 6, 18, and 35 over 4-hour intervals and on days 49, 63, 76, and 120 over 12-hour intervals. Air samples were collected at three heights above the soil surface (20, 80, and 160 cm) from two masts (spaced 12 m apart) near the center of the field. The masts (with three samplers/mast) were located to provide an adequate fetch length (100:1) for profile measurement. From atmospheric trifluralin concentration profiles and accompanying microclimate data, trifluralin flux rates were calculated for each sampling interval, using the energy and momentum balance methods (Harper et al., 1976). Only those rates computed by the momentum balance method are reported in this paper. Total daily fluxes were obtained by summing the values for each sampling interval.

The air-sampling system for monitoring atmospheric concentrations of trifluralin was similar to the type reported by Caro et al. (1971). A standard 250-ml gas-washing bottle containing a fritted glass cylinder was used as the vapor trap. The trap, wrapped in aluminum foil to protect against trifluralin photodecomposition, contained 100 ml of ethylene glycol previously washed with hexane and benzene to remove impurities that might interfere with gas chromatographic analysis. Air was drawn by vacuum through three traps simultaneously. Airflow through each trap was monitored and controlled independently with a rotometer-type flowmeter at flow rates of 6 liters/min.

The traps were removed at the end of each sampling period and transported to the laboratory for extraction and analysis. The ethylene glycol was transferred with washings to a separatory funnel, and trifluralin was extracted with 25 ml of benzene. The ethylene glycol was discarded and the benzene was washed twice with water, dried with anhydrous Na_2SO_4, and made to volume for gas chromatographic analysis. Samples were stored in the dark until gas chromatographic analysis could be completed. Calculations were adjusted for trapping efficiency and extraction recoveries of 90% each. The detection limits for trifluralin in air were 5 to 10 ng/m^3 for 4-hour sampling intervals and 2 to 3 ng/m^3 for 12-hour intervals.

Soil was sampled for trifluralin determinations at the beginning of each air-sampling interval at two depths: 0 to 0.5 cm, using a 15-cm trough-shaped spatula (0.5 cm deep); and 0 to 7.5 cm, using a 2-cm diameter tube sampler. Samples were randomly collected from 12 to 15 sites within two previously selected sampling areas and composited by area for analysis. Fifty grams of soil were extracted by shaking with three 50-ml portions of hexane-acetone (41/59 vol/vol). Combined extracts were transferred to a separatory funnel and washed twice with 50-ml portions of water. The remaining hexane was passed through a florisil cleanup column and collected in a 100-ml volumetric flask for gas chromatographic analysis. Trifluralin recovery from soil was 95% and the data were adjusted accordingly.

The amount of trifluralin in the hexane and benzene extracts, for soil and air samples, respectively, was quantified by peak heights using a dual-column, Micro-Tek Model 220, gas chromatograph equipped with a ^{63}Ni electron-capture detector. Determinatio were made on two glass columns (6 mm by 180 cm): (i) 10% DC 200 on 80/100 mesh Chromosorb W; and (ii) 11% OV-17 + QF- on 80/100 mesh Gas-Chrom Q. The carrier gas was prepurified N at a 60 ml/min flow rate. Inlet, oven, and detector temperature were 220, 180, and 260C, respectively.

In addition to microclimate measurements, pan evaporation and precipitation were recorded at the experimental site during th study. Official weather service readings for maximum and mi mum temperatures and daily wind movement were obtained fro a nearby location.

RESULTS AND DISCUSSION

Climatic data for each day of sampling and the previou day are shown in Table 1. The data presented are typica seasonal measurements for this location in Georgia. N unusual extremes in weather conditions occurred durin

Table 1—Climatic data and weather conditions for selected days during the study

					Air temperature		
Date	Sample day	Rainfall	Evaporation	Wind	Maximum	Minimum	General conditio
		cm	cm	km	°C	°C	
15 June	1	--	0.53	24	30.0	19.4	Fair
16 June	2	--	0.76	43	30.6	19.4	Fair
19 June	--	--	0.86	23	31.1	19.4	
20 June†	6	0.93	0.43	18	28.9	21.1	Cloudy, overcast
1 July	--	--	0.71	31	32.2	20.0	
2 July	18	--	0.64	19	32.8	20.6	Fair
18 July	--	--	0.68	43	25.6	19.4	
19 July‡	35	0.08	0.33	2	28.9	21.1	Cloudy, overcast
1 Aug.§	--	0.64	0.41	32	30.6	21.7	
2 Aug.	49	–	0.36	5	28.3	21.7	Cloudy, overcast
15 Aug.	--	--	0.69	31	30.6	20.6	
16 Aug.	63	--	0.58	13	30.0	18.3	Fair-pa cloudy
28 Aug.	--	--	0.61	30	32.8	17.2	
29 Aug.	76	--	0.69	24	32.8	17.2	Fair
11 Oct.	--	--	0.56	--	23.3	12.2	
12 Oct.	120	--	0.61	--	21.7	11.1	Fair

† Rainfall from 1326–1355 EDT. Skies partly cloudy and clearing after 1400.
‡ Rainfall from 0900–1045 EDT. Skies clearing after 1600.
§ Rainfall from 1745–1905 EDT.

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[3] Trade names and company names are given for the benefit of the reader and do not imply preferential endorsement by the U. S. Department of Agriculture over similar products or firms.

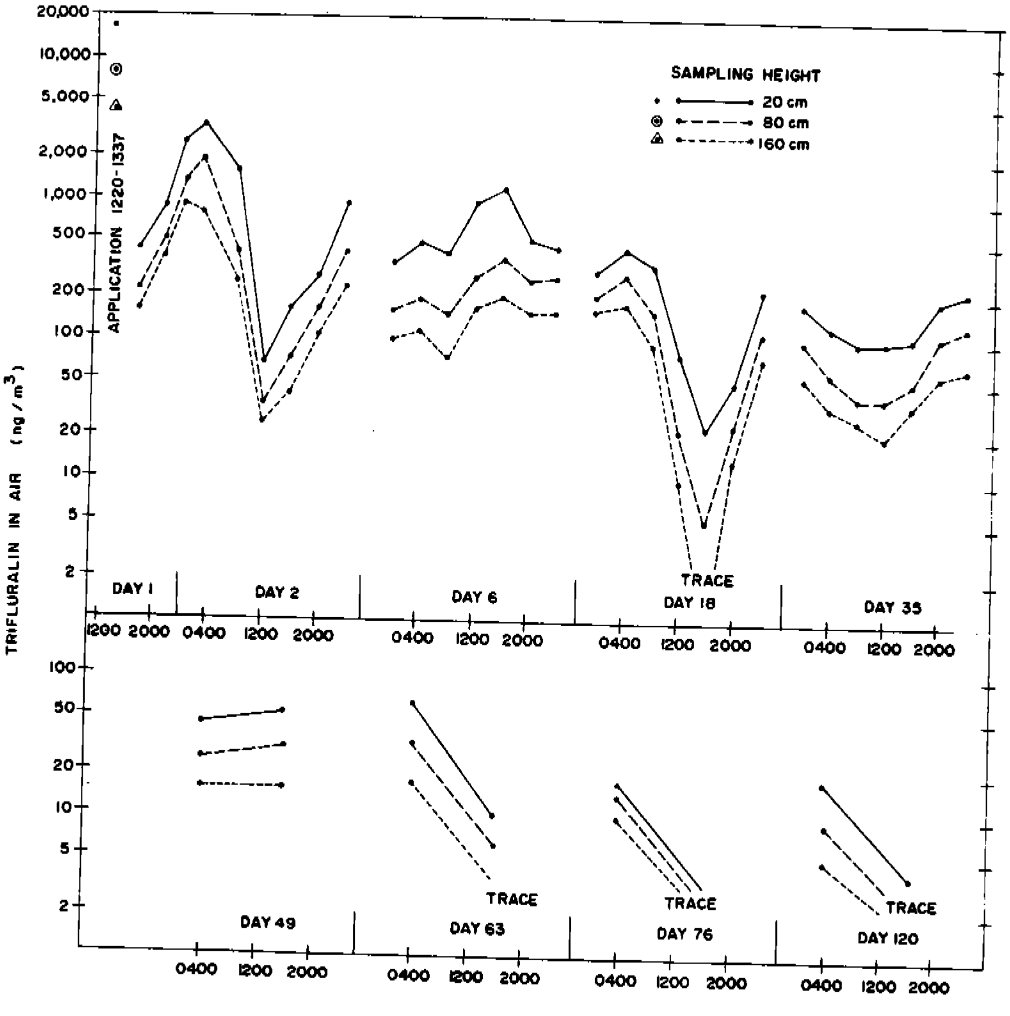

Fig. 1—Trifluralin atmospheric concentrations 20, 80, and 160 cm above the soil on 9 sampling days during the season.

any of the air-sampling periods during the 120-day study. There was rainfall immediately before or during three of the sampling periods.

Changes in atmospheric trifluralin concentrations at three heights above the soil are shown for 9 sampling days in Fig. 1. Points shown are average values for air samples taken at the same height from two masts and are the midpoints of 3-, 4-, or 12-hour intervals, except for the 77-min sampling period during application and incorporation on day 1. There were distinct concentration gradients throughout the study with the concentrations highest at the lowest sampling levels.

Trifluralin air concentrations were highest during the application and incorporation period when a level of 16,500 ng/m^3 was recorded at the 20-cm sampling height. Air concentrations measured during the application period are shown as isolated points in Fig. 1, since conditions during this period were distinctly different from all other time intervals sampled. Samples were collected from the time spraying started until all the trifluralin had been incorporated. Thus, these measurements reflected the combined effects of spray drift, vaporization from spray droplets, and volatilization from the soil surface before and during trifluralin soil incorporation.

Generally, air concentrations decreased rapidly during the first month. After incorporation, trifluralin concentrations in air at 20 cm reached a maximum of 3,400 ng/m^3 at 0400 on day 2 (Fig. 1), 1,150 and 470 ng/m^3, respectively, on days 6 and 18, and after day 35 maximum concentrations never exceeded 100 ng/m^3.

The seasonal trends in average daily trifluralin air concentrations at the 80-cm height and in trifluralin soil concentrations at two depths (0 to 0.5 and 0 to 7.5 cm) are shown in Fig. 2A and 2B. These data clearly show that soil and air concentrations decreased with time during the season. However, average daily trifluralin air concentrations (Fig. 2A) did not satisfactorily indicate the possible range differences in levels at any given time daily (Fig. 1).

Figure 2B shows that during the first 35 days the 0- to 0.5-cm surface soil samples had a higher trifluralin content than samples at the 0- to 7.5-cm depth. After 35 days, the trifluralin levels at the two sampling depths were similar. The higher initial levels in the surface samples were due to nonuniform incorporation. Previous studies with the incorporator used in this study showed that 90% of a soil-incorporated herbicide remained in the upper 2.5 cm, with concentrations rapidly decreasing to the 7.5-cm level. Our observed soil trifluralin dissipation rate was

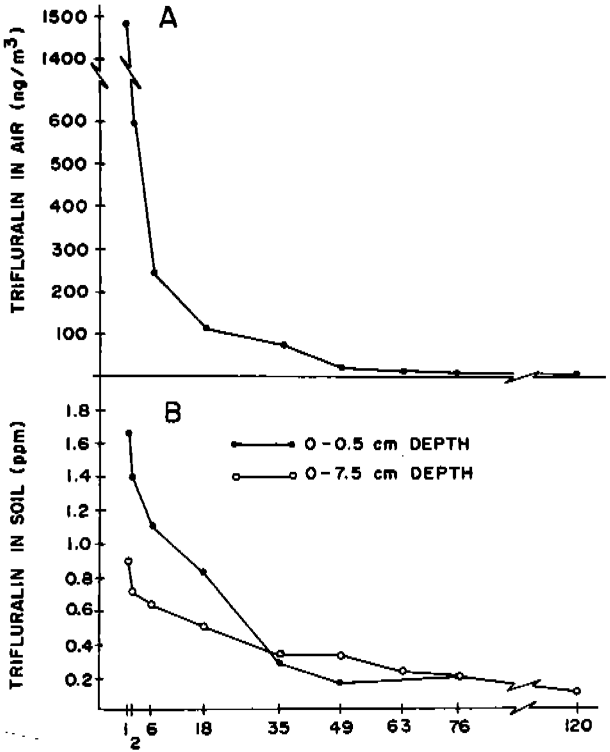

Fig. 2—Average daily trifluralin concentrations in air (at the 80-cm height) and in soil (at the 0- to 0.5- and 0- to 7.5-cm depths) over 120 days.

comparable with those reported previously by other researchers. Savage (1973) reported that soil trifluralin concentrations decreased rapidly after application and reached low residual levels of < 0.1 ppm in 3 to 4 months. Smith and Wiese (1973) reported soil levels of about 0.1 ppm, 1 month after trifluralin soil incorporation in the field. Probst et al. (1967) showed that after 29 and 43 days, 39 and 20%, respectively, of the original trifluralin remained in the soil.

Under certain atmospheric conditions air concentrations of trifluralin varied considerably (Fig. 1). For example, at the 20-cm level on day 2, the trifluralin air concentrations decreased from the maximum of 3,400 ng/m^3 at 0400 to 60 ng/m^3 at 1200, and on day 18 air concentrations ranged from a nighttime high of 470 to 23 ng/m^3 during the day. We observed very large decreases from nighttime to daytime levels like these on 5 sampling days. In contrast, on days 6, 35, and 49 the sharp decreases between night and day trifluralin concentrations did not occur, and on day 6 the highest trifluralin levels were measured during the day. These latter 3 sampling days differed from the others primarily because rainfall occurred either just before or during the sampling period (Table 1) and soil moisture was generally higher (Harper et al., 1976). Willis et al. (1971) reported that changes in atmospheric concentrations of some pesticides seemed to be related to climatological differences. In another field study, Willis et al. (1972) showed that soil moisture affected dieldrin volatilization losses. Spencer and Cliath (1974) showed in the laboratory that the potential volatility of trifluralin was 3,000 to 5,000 times greater in moist than in air-dry soil. Air concentrations of pesticides under field conditions can be influenced by many factors, including soil moisture, wind, temperature, and relative humidity. In this same study Harper et al. (1976) examined in detail the relationships between these variables and trifluralin volatilization and concluded that surface soil moisture was the major factor influencing trifluralin air concentrations and fluxes. On days when the surface soil was dry, trifluralin concentrations dropped sharply. The influence of increased moisture on trifluralin volatilization is clearly seen on day 6 (Fig. 1). A 0.93-cm rain fell at 1326, wetting the soil surface and evidently promoting volatilization, resulting in maximum aerial concentrations during the mid-day and afternoon sample periods for that day.

Trifluralin present at the soil surface and in the vapor phase after volatilization would be subject to degradation by ultravoilet light and likely there was some trifluralin photodecomposition under our study conditions. Losses by this pathway could have contributed to the decreased trifluralin air concentrations that we observed during the daytime for some of the sampling periods, but we were not able to confirm this.

Figure 3 shows volatilization rate losses expressed a trifluralin flux (in g ha^{-1} day^{-1}), and cumulative losses during the 120-day season. We calculated losses for each sampling time interval, utilizing the atmospheric conce tration data of Fig. 1, with accompanying microclim tological measurements, as described by Harper et a (1976). Trifluralin flux generally decreased with tim during the season, when it was expressed on an averag daily basis. Flux during the application period dominate that computed for day 1. During the 77-min applicatio period, the rate was 722 g ha^{-1} day^{-1}, whereas the averag flux for the remainder of that day was 10 g ha^{-1} day The estimated loss for the application period was 38.6 ha and for the remainder of day 1 (about 10.5 hours), 4 g/ha. Cumulative losses for the season, estimated as t integral of the flux rate curve, were 251 g/ha, excludi the application period loss. The flux rate for day 6 w slightly higher than that computed for day 2, probab because of the influence of rainfall that day which caus higher daytime atmospheric concentrations of triflural and increased volatilization rates. Actual seasonal loss may also differ slightly from that estimated, due to oth rainfall events.

Table 2 summarizes seasonal trifluralin losses into th atmosphere and estimated losses by other pathways. W estimated the seasonal volatilization loss, excluding th for the application period, as 22.4% of the applied her cide. Vapor losses during the application period we greater than during any other period of the study a amounted to 3.5% of the herbicide applied. Thus, to calculated atmospheric losses for the season were 25. of the total applied herbicide, with 13 and 15% of t atmospheric loss during application and through day 1, spectively. About half was lost during the first 9 da and 90% during the first 35 days.

Although our data indicate that trifluralin volatilizati losses were relatively high during application, as compa with other periods, an application loss of only 3.5% dicates that the application was quite efficient. Other searchers, using similar ground-type sprayers to apply fluralin, have consistently reported $>$ 95% application

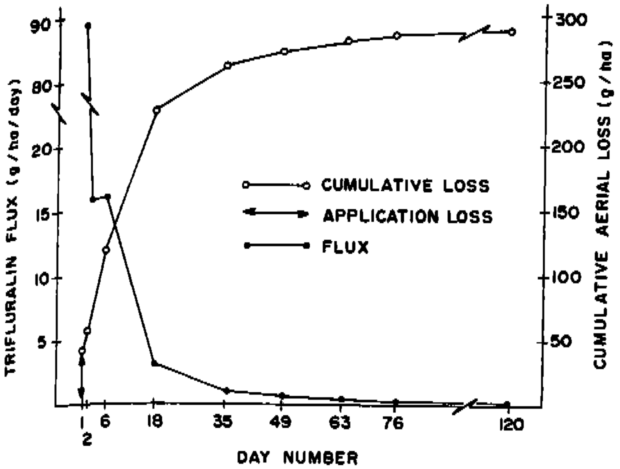

Fig. 3–Volatilization rate and cumulative losses of trifluralin over a 120-day period in the field.

ficiencies (K. E. Savage, personal communication). After 120 days, 89% of the originally applied trifluralin had disappeared from the 0-7.5 cm-soil zone (Table 2). The combined trifluralin losses by pathways other than volatilization amounted to 63%, almost 2.5 times more than the calculated atmospheric losses. Other work on this same experimental watershed demonstrated that trifluralin losses in runoff were < 1% (Unpublished data, USDA-ARS, Watkinsville, Ga. and Southeast Environ. Res. Lab., EPA, Athens, Ga.). Literature reports indicated that trifluralin is not readily leached in soils (Probst et al., 1967; Anderson et al., 1968; Smith, 1972). This suggests that major trifluralin losses in this study probably occurred via other routes, perhaps by nonbiological or physicochemical decomposition, as suggested by Probst and Tepe (1969) and Messersmith et al. (1971), and by microbial action (Parr and Smith, 1973).

Our calculated cumulative seasonal trifluralin losses (25.9%) represent volatilization from soil-incorporated trifluralin under the soil and climate conditions of this study. Pesticide loss rates will differ for other conditions and factors. Soil clay and organic matter contents influence pesticide adsorption in soil and, thus, control pesticide vapor pressures and potential volatilization (Spencer and Cliath, 1977). At our study site, the soil clay and organic matter content were low. Method of incorporation affects herbicide persistence and effectiveness, depending on the technique and incorporation depth (Robison and Fenster, 1968; Smith and Wiese, 1973). Savage and Barrentine (1969) showed that trifluralin persistence and volatilization were directly related to depth of soil incorporation. Since our incorporation method left most of the herbicide in the surface 2.5 cm, the measured aerial losses might be expected to be higher than those where more effective incorporation methods were employed. Additionally, volatilization losses were determined indirectly by mathematical methods, which have potential errors (Harper et al., 1976; Parmele et al., 1972). Thus, many factors must be considered, when extrapolating the reported volatilization losses to different situations.

Table 2–Trifluralin volatilization losses, amounts remaining in soil, and estimated losses via other pathways for the 120-day field test

Time, day	Cumulative volatilized: % of total applied	Cumulative volatilized: % of total volatilized	Remaining in soil†, % of applied	Estimated other losses, % of applied
Application	3.5	13.3	--	--
1	3.8	14.8	89	7.2
2	5.3	20.3	72	22.7
6	10.9	42.2	64	25.1
18	20.5	79.1	51	28.5
35	23.4	90.2	33	43.6
49	24.4	94.1	35	40.6
63	25.1	96.9	23	48.9
76	25.4	98.2	20	54.6
120	25.9	100.0	11	63.1

† Based on amount remaining in soil at a 0- to 7.5-cm depth as compared with an initial 1.0 μg/g level at application (rate was 1.12 kg/ha).

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BOOK REVIEW

Pollution Control in the Plastics and Rubber Industry

By Marshall Sittig. Noyes Data Corporation, Mill Road at Grand Avenue, Park Ridge, NJ 07656. 1975. 306 p. $36.00.

This book, No. 18 in Noyes Data Corporation's Pollution Technology Review Series, is a comprehensive treatise on manufacturing processes, product finishing, recovery and recycling of wastes, and pollution control in the plastics and rubber industries. These industries are among the fastest growing sectors of our economy and are associated with monumental problems of air pollution, water pollution, and solid waste disposal. While manufacturing processes cause some air pollution, it is likely that a more serious air pollution problem results from incineration of plastics and rubber wastes. Water pollution problems result primarily from manufacturing operations. The author points out that the disposal of solid wastes from these industries is perhaps the greatest problem of all.

The magnitude of the solid waste disposal problem is discussed in considerable detail. For example, on a weight basis the percentage of plastic materials in refuse is presently $<2\%$ compared with paper products which account for about 35% of the total. However, by 1980 the increased use of plastics in packaging could increase this fraction to 12%. Nevertheless, the author substantiates that if household products were packaged in materials other than plastic it would mean an even greater contribution from packaging to the solid waste load, on both a weight and volume basis.

Another major difference between these industries relevant to the solid waste disposal problem is that many plastic wastes are recyclable whereas recycling and reuse of rubber products (the major fraction of which is comprised of old tires) depends on retread tire sales and is therefore a very limited activity. For example, in 1974 new rubber usage in the United States was 3,311,000 long t while only 150,000 tons of old rubber was reclaimed, thus lea a sizable disposal problem. Unfortunately, the cost advantage reprocessing rubber wastes have not been sufficiently high to sti late recycling. The author feels that the most practical use rubber wastes (particularly discarded tires) is raw materails recov by distillation, or energy recovery. He recommends that expand research and development programs be initiated by both private dustry and the Federal Government to achieve economical or le cost methods for tire processing and resource recovery.

The book is well written and thoughtfully organized for gre comprehension than most books of this type. The table of conte serves as a subject index and provides easy access to the infor tion presented. The book contains numerous tables, schematic grams, and flow charts which deal with plastic and rubber ma facturing processes, pollution control and solid waste disposal, recovery systems. It also contains an index of patentees, a list references to highly relevant government reports, and a section future trends toward the resolution of air and water pollution pr lems and solid waste disposal problems in the plastics and rub industries.

The advanced composition and production techniques develo by the publisher of this series have successfully circumvented long periods of delay and "incubation" between manuscript completed book that are considered normal in conventional b publishing. In a world where technology changes rapidly it provided the user with an effective compilation of up-to-dat formation on a number of technical subjects. The book shoul widely acquired by research and university libraries and should as a valuable reference to scientists and engineers concerned these problems.—J. F. PARR, *USDA-Agricultural Research Ser Beltsville, MD 20705.*