Occurrence of Pesticides in Rain and Air in Urban and Agricultural Areas of Mississippi, April-September 1995

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ABSTRACT

In April 1995, the U.S. Geological Survey began a study to determine the occurrence and temporal distribution of 49 pesticides and pesticide metabolites in air and rain samples from an urban and an agricultural sampling site in Mississippi. The study was a joint effort between the National Water-Quality Assessment and the Toxics Substances Programs and was part of a larger study examining the occurrence and temporal distribution of pesticides in air and rain in the Mississippi River Basin. Concurrent high-volume air and wet-only deposition samples were collected weekly. The air samplers consisted of a glass-fiber filter to collect particles and tandem polyurethane foam plugs to collect gas-phase pesticides. Every rain and air sample collected from the urban and agricultural sites had detectable levels of multiple pesticides. The magnitude of the total concentration was 5 to 10 times higher at the agricultural site as compared to the urban site. The pesticide with the highest concentration in rain at both sites was methyl parathion. The pesticide with the highest concentration in the air samples from the agricultural site was also methyl parathion, but from the urban site the highest concentration was diazinon followed closely by chlorpyrifos. A metabolite of *p,p*'-DDT, *p,p*'- DDE, was detected in every sample from the agricultural site and in more than half of the air samples from the urban site more than two decades since DDT was banned from use in the United States.

INTRODUCTION

Pesticides are widely used in the United States to protect crops from pests, to reduce crop yield loss, and to increase the comfort and safety of citizens. Although the use of pesticides has resulted in increased crop production and other benefits, there is concern about the ultimate fate of pesticides. Pesticides have the potential to contaminate the hydrologic cycle when they move from their point of application. One potential path for off-site movement is through the atmosphere. Small amounts of pesticides can be transported long distances through the atmosphere and deposited into aquatic and terrestrial ecosystems far from their point of use (Majewski and Capel, 1995). Atmospheric transport can occur in the gas phase through volatilization or in the particulate phase when attached to dust particles, or a combination of both depending on the pesticide's physical and chemical properties. After introduction into the atmosphere, pesticides can be degraded, transported, and redeposited. Deposition can be either wet such as with rain or snow, or dry such as gaseous sorption and particle fallout.

There have been several studies that have examined the movement of pesticides in the atmosphere, and an excellent review of many of the major studies is in Majewski and Capel (1995). In Mississippi, there have been a limited number of studies on the transport of pesticides in the atmosphere. Many of these studies have dealt with the volatilization of pesticides after application (Hollingsworth, 1980; Willis and others, 1980; Harper and others, 1983; and Willis and others, 1983). Hollingsworth (1980), examined volatilization of trifluralin after incorporation, the other studies examined toxaphene or DDT or both. Arthur and others (1976) collected weekly air samples and analyzed them for a suite of pesticides, most of which have since been discontinued in the

United States. There have been a few national studies that have included agricultural and urban sites in Mississippi, (Tabor, 1965; Stanley and others, 1971; and Kutz and others, 1976), but these studies focused on pesticides that were then in use, most of which are no longer used in the United States.

In June 1994, Majewski and others (1998) collected air samples during a cruise up the Mississippi River from New Orleans, Louisiana to St. Paul Minnesota. This was a precursor to the current study and used the same equipment and analytical techniques. Their results indicated that the occurrence and atmospheric concentration of the observed pesticides were most closely related to their use within 40 kilometers of the river. Additionally, some pesticides heavily used in urban areas such as chlorpyrifos, diazinon, and malathion had their highest concentration near urban areas. There have been no other studies on pesticides in the atmosphere in Mississippi in recent years. The purpose of this paper is to present the results of a study of pesticides in rain and air from April 12 to September 19, 1995, collected from an urban and an agricultural setting in Mississippi by the U.S. Geological Survey (USGS).

Sampling Sites

The urban sampling site is located in Hinds County, Mississippi, in a residential neighborhood of the south Jackson, metropolitan area. The site was chosen to represent urban air and is several kilometers from the nearest agricultural field.

The agricultural sampling site is in the center of a catfish pond complex near the town of Rolling Fork in Sharkey County, Mississippi. This area is in the Mississippi River Alluvial Plain and is one of the most intensively farmed areas in the United States. The major crops were, soybean, cotton, corn, and rice. The site location was selected to minimize the influence of direct application of pesticides to nearby fields. The nearest agricultural field was approximately a kilometer away.

Sampling Procedures

Weekly samples of wet-only deposition were collected by using a modified Aerochem Metric Precipitation Collector (any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government). This collector is equipped with a moisture sensor that triggers the lid of the collection bucket to open when rain begins and to close when the rain ends. The collector was modified by installing a Teflon-coated funnel in the collection bucket and attaching a Teflon tube from the funnel through the bottom of the bucket into the top of a small refrigerator and into a glass bottle. The inside of the refrigerator was maintained at 4°C.

Samples were collected weekly, if there had been enough precipitation. Samples were transported to the USGS office, and a 1-L aliquot was withdrawn and passed through a C-18 solid phase extraction cartridge for isolation of the compounds of interest. The cartridge was then sent to the National Water Quality Laboratory (NWQL) in Arvada, Colo. Samples were eluted from the cartridges with solvent and analyzed for 47 pesticides and pesticide degradates by gas/chromatography mass/spectrometry (GC/MS) using selected ion monitoring (Zaugg and others, 1995).

The last rain sample from the urban site was collected during the week of August 15-22 and the last rain sample for the agricultural site was the week of August 29 through September 5. During the week of April 19-26, more than 20 centimeters (cm) of rain fell at both sites. The sample bottles were designed to hold about 13 cm of rain. At the agricultural site, the sample bottle was replaced on April 22; however, the urban site could not be accessed, and the sample bottled overflowed. In all, there was sufficient rainfall for 16 weekly samples from the urban site and 15 weekly samples and 1 midweek sample at the agricultural site out of a possible 24 weekly samples.

The air samplers consisted of a baked glass-fiber filter (GFF), 21.6 cm x 27.9 cm, to collect particles and tandem polyurethane foam (PUF) plugs, 8.9 cm diameter x 7.6 cm, to collect gas-phase pesticides. The air was pulled through the GFF and then through the PUFs at about 1 cubic meter (m^3) per minute. The PUFs were mounted in tandem and analyzed separately to estimate the efficiency of the two PUFs for the collection of gas-phase pesticides. If a pesticide was detected on the first PUF and not on the second, it was assumed that the gas-phase pesticide was completely collected by the first PUF. If, however, there was an equal or larger amount of the pesticide on the second PUF, as on the first, then it was assumed that extraction of the pesticide by the PUFs was not complete and the concentrations derived from the PUFs must be considered a minimum. Diazinon, molinate, and trifluralin had concentrations on the second PUF equal to or more than on the first PUF. These concentrations are considered minimums; the actual concentrations were higher. As a quality assurance measure the collection efficiencies were evaluated from a spiked sample and are reported in Majewski and others (1998). The collection efficiencies for most compounds were excellent except for those noted on table 1.

At the beginning of the study (April 12, 1995) the air sampler was programmed to sample air continuously for 4 hours during the day; later (May 5, 1995), this was changed to 5 minutes out of every hour to better represent average air concentrations. The GFF and the PUFs were replaced after 7 days. The GFFs were analyzed separately to provide an estimate of the particle and distribution of the pesticides. The last air samples at both sites were collected for the week of September 12-19. At the agricultural site, equipment failures prevented the collection of samples for the weeks of July 5-12, July 25-August 1, and August 1-8.

The GFFs and PUFs were sent on ice to the NWQL where they were extracted with 36.5 percent ethyl acetate in hexane for 16 hours using a soxhlet apparatus. The extract was dried using sodium sulfate and reduced to 0.5 mL using a Kuderna-Danish concentrator followed by nitrogen gas evaporation. The extract was passed through a Pastuer pipet column containing 0.75 g of fully activated florisil overlain with 1 cm of powdered sodium sulfate. Pesticides were eluted using 4 mL of ethyl acetate into a test tube containing 0.1 mL of a perdeuterated polycyclic aromatic hydrocarbon internal standard solution. The extract was evaporated to about 150 mL using nitrogen gas, transferred to autosampler vial inserts using a 100 mL toluene rinse, and analyzed by the same GC/MS procedure used for the rain samples.

RESULTS OF ANALYSES

The pesticides for which the rain and air samples were analyzed are listed in table 1. The agricultural pesticide-use rankings for Mississippi are also listed along with possible urban use. Descriptive statistics for occurrence and concentrations of several of the frequently detected pesticides are listed in table 2.

Rain Samples

Twenty-five of 47 measured pesticides were detected at least once in rain samples from the urban site (table 1). Methyl parathion was measured in the highest concentration. Methyl parathion is an insecticide that is used very heavily on row crops in Mississippi, but it is not registered for use in urban areas. Five pesticides (4 insecticides and 1 herbicide) were measured in more than 50 percent of the rain samples from the urban site: carbaryl, chlorpyrifos, diazinon, methyl parathion, and atrazine. No pesticide concentration exceeded 0.5 microgram per liter (μg/L).

Twenty-six of 47 measured pesticides were detected at least once in rain from the agricultural site (table 1). The pesticide measured in the highest concentration was methyl parathion. Eight pesticides (1 insecticide and 7 herbicides) were detected in more than 50 percent of the rain samples from the agricultural site; methyl parathion, atrazine, cyanazine, metolachlor, molinate, pendimethalin, propanil, and trifluralin. There were three pesticides measured at concentrations higher that 0.5 μg/L; they were atrazine (0.83 μg/L), methyl parathion (8.6 and 22.9 μg/L), and propanil (1.8 μg/L).

Air

Twenty-one of 47 measured pesticides were detected in air (GFF and PUFs) from the urban site (table 1). The most frequently detected pesticide was chlorpyrifos, followed by trifluralin and diazinon. Four pesticides (3 insecticides and 1 herbicide) were detected in more than 50 percent of the samples; chlorpyrifos, diazinon, *cis*-permethrin, and trifluralin. Methyl parathion was measured in 11 of the 24 samples.

Twenty-seven of 47 pesticides were detected in air from the agricultural site (table 1). The most frequently detected pesticides were trifluralin and *p,p'*-DDE, a metabolite of DDT; they were detected in every sample. Four other pesticides were also detected in more than 50 percent of the air samples: atrazine, methyl parathion, molinate, and propanil.

OCCURRENCE OF PESTICIDES

Previous studies of pesticides in the atmosphere have indicated that the highest concentrations typically are seasonal and correspond to local use, usually originating within tens of kilometers of the collection point, and that there is a component related to long-range transport, usually only identifiable before or after use and planting season. Because sampling occurred during the growing season, the concentrations reported here are probably related to local use. This would indicate that a component of the pesticides in the air at the urban site would be from agriculture, as there is intensive agriculture within a 100-kilometer radius of Jackson, Mississippi.

Pesticide use for agricultural purposes is well documented; however, urban pesticide use, which includes consumer applications in and around the home and professional application in industrial settings, golf courses, parks, cemeteries, roadways, and railroads, is not well documented. Therefore, comparisons of the occurrence of pesticides in the atmosphere as the occurrence relates to local use, while practical for the agricultural sites, is more difficult for an urban setting. In general, the distribution of the detected pesticides in rain and air, within the urban and agricultural data in this study is quite different. The concentrations of pesticides in rain and air, in general, are higher at the agricultural site than at the urban site, and the types of pesticides detected reflect their local use, although in the case of the urban site there were some agricultural pesticides detected. In urban rain and air, the insecticides carbaryl, chlorpyrifos, and diazinon were detected more frequently than at the agricultural sites. These insecticides are used heavily in the South for fire ant and termite control; their use in agricultural settings is limited. [Note: Although chlorpyrifos is used heavily in agricultural settings in other States, its use in Mississippi has been limited since 1993, because of concerns about residues detected in farm-raised catfish (R. McCarty, Bur. of Plant Industry, written commn., 1997).]

Pesticides in Rain

The total pesticide concentrations in rain for samples collected at the urban and agricultural site are shown in figure 1. The stacked bars show concentrations in µg/L for atrazine, carbaryl, methyl parathion, propanil, and other. The other category is and aggregation of those pesticides infrequently detected. The total pesticide concentrations were 5 to 10 times higher at the agricultural site, reflecting the heavy use of agricultural chemicals on local crops. The pesticides making up a large proportion of the total concentrations in rain at the urban site were atrazine, carbaryl, methyl parathion, and propanil. Because methyl parathion and propanil do not have any legal urban uses, it is assumed that these pesticides were transported from agricultural areas. Methyl parathion and propanil, respectively, are the first and sixth heaviest used pesticides in Mississippi. The total pesticide concentrations in rain at the agricultural site are dominated by atrazine, methyl parathion, and propanil, with some metolachlor and molinate. In two rain samples (weeks beginning June 27 and August 1), the concentrations of methyl parathion, 22.9 and 8.6 µg/L, were very high compared to the concentrations of other pesticides in rain. The highest concentrations of methyl parathion in air, 55.6 and 62.5 nanograms per cubic meter (ng/m^3), occurred during the weeks of August 8 and August 15, respectively, corresponding to weeks with little or no rain. The week of the highest concentration in rain (June 27, 22.9 µg/L), the concentration in the air sample was 10.8 ng/m^3. The data in table 2 indicate that methyl parathion is present in rain and air. Methyl parathion must be easily scavenged from the air by raindrops but will persist in the atmosphere without rain and, therefore, is available to be transported from the point of application. This is consistent with the presence of methyl parathion at the urban site.

In a paired study that looked at the differences in triazine concentrations (atrazine, cyanazine, simazine, terbutylazine) between a rural site and an urban site, Chevreuil (1996) noted that there was no difference in diversity and abundances of these herbicides in bulk deposition (rain and particulate phases) between the two sites. This was attributed to the fact that the urban site, located in Paris, France, is relatively small and surrounded by an area of intense agriculture. The concentrations in the French study were similar to those found at the urban and rural sites in Mississippi. From figure 1 and table 2, it appears that there is a difference in concentrations of atrazine and cyanazine between the urban and agricultural site, although there are too few data above the reporting level to determine if this is a statistically significant difference. However, when examining the total pesticide concentrations in rain, it is clear that there is a difference between the urban and agricultural sites. Nations and Hallberg (1992) noted a difference in pesticide concentrations between an urban and a rural site in Iowa. The herbicides were detected as frequently at both sites, but the rural site had higher concentrations than the urban site. The urban site had most of the insecticide detections (fonofos, malathion, and methyl parathion); this was related to urban lawn and garden use. The concentrations of the corn and soybean herbicides in the Iowa study were higher than those measured at the agricultural site in Mississippi.

Nations and Hallberg (1992) and Chevreuil (1996) noted an annual cycle for the triazines: a rapid rise of the concentrations corresponding with spring planting and a decrease to a minimum by the end of summer. Although a similar cycle was noted in this study in Mississippi for the triazine herbicides, the total concentration of pesticides does not appear to follow this cycle as closely. There are multiple pesticide concentration peaks corresponding to varying planting dates for different crops, followed by post-emergent applications and applications of insecticides for pest control.

Pesticides in Air

The pesticide concentrations in air at the urban and agricultural sites are shown in figure 2. The stacked bars show air concentrations in ng/m^3 for carbaryl, chlorpyrifos, diazinon, methyl parathion, pendimethalin, trifluralin, and other. The other category is an aggregation of pesticides infrequently detected. The other category for the air samples at the agricultural sites collected during the weeks of May 3, May 10, and May 16 was dominated by thiobencarb and propanil. Total pesticide concentrations in air (GFF and PUFs combined) were higher at the agricultural site, and the makeup of the total concentrations was different. Total pesticide concentration in air at the urban site was dominated by chlorpyrifos and diazinon, with smaller amounts of carbaryl, methyl parathion, and trifluralin. At the agricultural site, the total pesticide concentration in air was dominated by a number of different pesticides at different times. At the start of the study, in April, the herbicides pendimethalin and trifluralin made up the majority of the total concentrations. At the beginning of May, the two major pesticides were the rice herbicides propanil and thiobencarb. Towards the end of the study, the insecticide methyl parathion was the dominant pesticide. The occurrence of these pesticides in the air was related to local application times on cotton and rice.

In two studies conducted in the late 1960’s and early 1970,s air was sampled for methyl parathion near Stoneville, Mississippi, about 70 kilometers north of Rolling Fork. Stanley and others (1971) collected 24-hour samples during 1967 and 1968. Most of the samples were collected during July through October, the high use period for methyl parathion. The range of concentrations of methyl parathion in air for the months of August and September was from 20.6 to 71.0 ng/m^3. The results for this study compare well with Stanley's data collected nearly three decades ago. Arthur and others, (1976) presented average monthly concentrations of methyl parathion for 1972-74. The average monthly concentrations of methyl parathion for August of 1972-74 were 217, 129, and 341, ng/m^3 for the three years, respectively. The concentrations of methyl parathion in air from Arthur's study are higher than those presented in this study. The authors for Arthur's study noted some anomalous results in that the concentrations of methyl parathion in air in 1973 was much higher than in 1972 overall, although there had been a 38 percent reduction in its use from 1972 to 1973.

Stanley and others (1971) detected *p,p*'-DDE in concentrations ranging from 2.6 to 7.1 ng/m^3 during April through September 1967. The range of *p,p*'-DDE concentrations at the agricultural site in this study was from 0.13 - 1.1 ng/m^3, lower than Stanley's, but still significant considering that DDT was banned in the United States in 1972. These results indicate that a persistent *p,p*'-DDT degradation product was still measurable in the air more than two decades after DDT use was banned in the United States.

Factors Affecting the Occurrence of Pesticides in Rain

There are numerous mechanisms that can deliver organic compounds to the atmosphere, such as volatilization, wind erosion of soil particles to which pesticides are attached, and direct spraying of the compound to the atmosphere during pesticide application. Once in the atmosphere, a compound will distribute among the aqueous, gaseous, and particulate phases based on the physical and chemical properties of the compound, including water solubility and vapor pressure, and on the conditions of the atmosphere such as temperature, moisture content, and the type and concentration of particulate matter. The phase distribution of the compound strongly affects the behavior, transport, and ultimate fate of the compound in the atmosphere. The water solubility, vapor pressure, and Henry's law constant for selected compounds that were frequently detected at either the urban or agricultural site or both are listed in table 3.

Chlorpyrifos, *p,p*'-DDE, diazinon, methyl parathion, molinate, and trifluralin were detected largely or exclusively on the PUF and rarely on the GFF and, thus, were primarily in the gaseous phase in air. Wet deposition of these pesticides should be dominated by gas scavenging and related to the Henry's law constant for the pesticide. Of these pesticides, chlorpyrifos, *p,p*'-DDE, and trifluralin have relatively lower water solubilities and higher Henry's constants. Consequently, less (gaseous) pesticide mass should be scavenged, resulting in less frequent detections in rain relative to other pesticides having comparable air concentrations and detection levels in rain but lower Henry's constants. This appears to be the case for *p,p*'-DDE. However, the frequency of detection in rain for chlorpyrifos at both the urban and agricultural sites and for trifluralin at the agricultural site, compared with the frequency of detection in air, was not different from the frequency of detection in rain of diazinon, molinate, and methyl parathion, pesticides with lower Henry's constants and higher water solubilities.

Reduced air concentrations are partly caused by dilution effects as air parcels are transported away from pesticide application sites. Further, pesticides such as trifluralin and molinate are susceptible to photochemical degradation reactions (Grover, 1991), the rates for which can be stimulated by increased concentrations of oxidants, such as ozone, that typically are present in higher concentrations in urban versus rural atmospheres (Finlayson-Pitts and Pitts, 1986). Trifluralin and molinate concentrations in air at the urban site were approximately one order of magnitude lower than at the agricultural site. These lower concentrations in air resulted in reduced frequencies of detectable rain concentrations relative to the agricultural site.

Atrazine and propanil were detected in substantial concentrations in both the gaseous and particulate phases in air at the agricultural site. These pesticides have relatively high water solubilities and low Henry's constants. Therefore, scavenging of these pesticides by rain from both sources is important. Detection of these pesticides in rain was more frequent than in air at both sites.

SUMMARY AND CONCLUSIONS

Every rain and air sample collected from an urban and an agricultural site in Mississippi during April-September 1995 had detectable levels of multiple pesticides. The magnitude of the total concentration was 5 to 10 times higher at the agricultural site as compared to the urban site. The pesticide with the highest concentrations in rain at both sites was methyl parathion. Methyl parathion was also the pesticide in the highest concentration in air from the agricultural site, but at the urban site, the pesticide in the highest concentration in air was diazinon followed closely by chlorpyrifos. A metabolite of *p,p*'-DDT, *p,p*'-DDE, occurred in all of the air samples from the agricultural site more than two decades since DDT was banned in the United States. The occurrence of pesticides in rain and air at the agricultural site was related to the timing of application and local use. The occurrence of pesticides in urban rain and air for which there are no legal uses in an urban area was related to transport through the atmosphere from areas of heavy agricultural use.

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Table 1. Pesticide detections in rain and air from agricultural and urban sites in Mississippi, April – September 1995

[h, herbicide; X, detected; ND, not detected; m, metabolite; NR, not reported; i, insecticide; NA, not applicable; dc, discontinued]

Pesticide	Urban detections		Agricultural detections		Rankings of agricultural use in Mississippi[1]	Urban use (1990) [2]
	Rain	Air	Rain	Air		
Acetochlor (h)	X[3]	ND[4]	ND	ND	NR	NR
Alachlor (h)	X	ND	X	ND	20[5]	NR
alpha-HCH (i)	X	X[4]	ND	X	NA	NR
Atrazine (h)	X	X	X	X	18	yes
Benfluralin (h)	ND	X	ND	ND	NR	NR
Butylate (h)	ND	ND	ND	X[3]	75	NR
Carbaryl (i)	X	X	X	X[3]	37	yes
Carbofuran (i)	X	ND	X	X[3]	38	NR
Chlorpyrifos (i)	X	X	X	X	30	yes
CIAT[6] (m)	X	X	X	X	NA	NA
Cyanazine (h)	X	X	X	X	9	NR
DCPA (h)	X	X[3]	X	X	94	yes
p, p'- DDE (m)	ND	X	ND	X	NA	NA
Diazinon (i)	X	X	X	X	92	yes
Dieldrin (i)	X[3]	X[3]	X	X	dc	dc
2,6-Diethylaniline (m)	ND	ND	ND	X	NA	NA
Dimethoate (i)	NA[7]	ND[4]	NA	ND	56	yes
CEAT[8] (m)	NA[7]	X[4]	NA	X	NA	NA
Disulfoton (i)	ND	ND[9]	ND	ND	34	yes
EPTC (h)	ND	ND[9]	X[3]	X	65	yes
Ethalfluralin (h)	ND	ND[9]	ND	ND	49	NR
Ethoprop (i)	ND	ND	X[3]	X	96	NR
Fonofos (i)	ND	ND	ND	ND	NR	NR

Pesticide	Urban detections		Agricultural detections		Rankings of agricultural use in Mississippi[1]	Urban use (1990) [2]
	Rain	Air	Rain	Air		
Lindane (i)	ND	X[3]	ND	X	102	NR
Linuron (h)	ND	ND	X[3]	ND	44	NR
Malathion (i)	X	X[9]	X	X	21	yes
Methyl Azinphos (i)	X	ND[4]	X	X	47	yes
Methyl Parathion (i)	X	X	X	X	1	NR
Metolachlor (h)	X	X[9]	X	X	12	NR
Metribuzin (h)	ND	ND	ND	X	27	NR
Molinate (h)	X	X[3]	X	X	23	NR
Napropamide (h)	ND	ND	ND	ND	101	NR
Parathion (i)	ND	ND	X[3]	ND	NR	NR
Pebulate (h)	X[3]	ND[9]	ND	ND	NR	NR
Pendimethalin (h)	X[3]	ND	X	X	13	yes
cis-Permethrin (i)	X[3]	X	ND	ND	77	yes
Phorate (i)	ND	ND	ND	ND	62	NR
Prometon (h)	X	NA[10]	X	NA	NR	yes
Pronamide (h)	ND	ND	ND	ND	NR	NR
Propachlor (h)	ND	ND	ND	ND	NR	NR
Propanil (h)	X	X	X	X	6	NR
Propargite I & II (i)	ND	ND[9]	ND	ND	NR	NR
Simazine (h)	X[3]	X	X	ND	87	yes
Tebuthiuron (h)	ND	NA[10]	ND	NA	NR	NR
Terbacil (h)	ND	ND[9]	X[3]	ND	NR	NR
Terbufos (i)	ND	ND	ND	ND	54	NR
Thiobencarb (h)	X	ND	X	X	31	NR
Triallate (h)	ND	ND[4]	ND	ND	NR	NR
Trifluralin (h)	X	X	X	X	3	yes

1 From Gianessi and Puffer, 1991, 1992a, 1992b
2 From Majewski and Capel, 1995
3 Detected once
4 Method performance data are not available
5 Gaps in rankings due to pesticides not included in this study
6 CIAT, chloroisopropylaminotriazine
7 Analyzed for in air only
8 CEAT, chloroethylaminotriazine
9 Recovery of spiked sample was less than 60 percent from Majewski and others, 1998.
10 Analyzed for in rain only

Table 2. Statistics on selected pesticides in rain and air
[rain units,micrograms per liter; gas and particulate units, nanograms per cubic meter; #, number of samples; %, percent of sample detections; max, maximum concentrations; med, median concentration; nd, not determined]

Pesticide	Phase	Urban				Agriculture			
		#	max	med	%	#	max	med	%
Atrazine	rain	16	0.096	0.006	69	16	0.83	0.02	75
	gas	24	nd	nd	0	21	2.6	nd	42
	particulate	24	0.019	nd	29	21	0.42	0.058	67
Chlorpyrifos	rain	16	0.009	0.005	63	16	0.04	<0.005	38
	gas	24	3.5	1.5	96	21	3.1	nd	38
	particulate	24	nd	nd	0	21	nd	nd	0
Cyanazine	rain	16	0.074	<0.013	31	16	0.32	0.008	56
	gas	24	0.61	nd	8	21	0.25	nd	5
	particulate	24	nd	nd	0	21	0.39	nd	24
Diazinon	rain	16	0.019	0.005	56	16	0.013	<0.008	13
	gas	24	8.4	0.14	50	21	1.4	nd	10
	particulate	24	0.2	nd	25	21	nd	nd	0
Methyl Parathion	rain	16	0.3	0.024	56	16	22.9	0.12	69
	gas	24	0.99	nd	46	21	62	2.5	71
	particulate	24	nd	nd	0	21	0.4	nd	29
Molinate	rain	16	0.025	<0.004	25	16	0.37	0.026	63
	gas	24	0.44	nd	4	21	3.4	0.076	62
	particulate	24	nd	nd	0	21	0.089	nd	5
Propanil	rain	16	0.14	<0.016	38	16	1.8	0.036	81
	gas	24	0.24	nd	13	21	7.6	0.37	57
	particulate	24	0.043	nd	21	21	4.3	0.54	62
p,p'-DDE	rain	16	<.006	<0.006	0	16	<.006	<.006	0
	gas	24	0.19	nd	33	21	1.1	0.67	100
	particulate	24	nd	nd	0	21	0.019	0.01	52
Trifluralin	rain	16	0.01	<0.002	13	16	0.024	0.007	69
	gas	24	0.76	0.028	88	21	5.5	0.81	100
	particulate	24	nd	nd	0	21	0.013	nd	5

Table 3. Water solubility, vapor pressure, and Henry's law constant (between 20 and 25°C) for selected compounds
[mole/m ^{3}, mole per cubic meter; Pa, pascal]

Compound	Subcooled liquid		Henry's law constant Pa m^3/mole
	Water solubility (mole/m^3)	Vapor pressure (Pa)	
Atrazine	4.48E+00	1.29E-03	2.87E-04
Chlorpyrifos	1.25E-03	2.19E-03	1.75E+00
Cyanazine	1.85E+01	5.21E-06	2.82E-07
Diazinon	1.25E-01	8.00E-03	6.41E-02
Methyl parathion	1.27E-01	2.67E-03	2.11E-02
Molinate	4.70E+00	7.46E-01	1.59E-01
Propanil	6.50E+00	2.36E-02	3.64E-03
p,p'-DDE	5.48E-04	4.36E-03	7.95E+00
Trifluralin	2.44E-03	9.84E-03	4.03E+00