

# **A Modeling Assessment of the Impact of Pesticide Application Methods and Tilling Practices on Emissions to the Atmosphere**

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## **ABSTRACT**

Atmospheric transport and deposition models are important tools for studying the atmospheric route for deposition of persistent organic compounds to terrestrial receptors. Emission rates are an extremely important input to these models and, to a large extent, determine the magnitude of the impact at receptors. Anthropogenic emissions to the atmosphere from industrial processes can generally be estimated from the activity rates of the processes giving rise to the emission. In the case of agricultural pesticides, however, the emission to the atmosphere following application is strongly dependent on meteorology which determines the moisture and heat processes in the soil. In addition, the method of pesticide application and tilling practices can be dominant factors in determining the emission rates from agricultural soils. This paper provides an assessment of the effects of agricultural practices on emission of pesticides to the atmosphere over a three year period following application. Three modes of pre-emergent pesticide application are examined; incorporation into the soil, sprayed application to the soil surface, and in-furrow application at the time of seed planting. While in-furrow application makes the pesticide initially unavailable at the soil surface, evaporation of moisture and subsequent tilling of the soil may bring the pesticide to the surface where it volatilizes. The percentages of applied pesticide lost to the atmosphere are compared for the three application methods, with and without tilling of the soil in the fall or spring. Results for twenty pesticides, representing a wide range of physical-chemical properties, are reported. The selected pesticides include some that are in current use in North America as well as those that have been banned or restricted but which may be in use elsewhere on the globe.

## **INTRODUCTION**

The atmospheric deposition of pesticides and other organochlorine compounds to water bodies such as the Great Lakes is well accepted as an important route leading to the accumulation of toxic pollutants in these and other water bodies. Several comprehensive monitoring studies<sup>(1)</sup> have established that there are significant air concentrations of many pesticides in the atmosphere over the Great Lakes and, with simultaneous measurements of the water concentrations, estimates can be made of the deposition and gaseous exchange rates of many pesticides with the atmosphere. Any strategy to manage the accumulation of toxics in the Great Lakes, however, must address the sources of emission to the atmosphere that give rise to the observed air concentrations in their vicinity. For pesticides and some other toxics, the attribution of air concentrations to sources of emission is extremely complex. While the primary sources of pesticides in the air are current applications to agricultural lands, emissions from residues in soils due to historical use have been identified as significant contributors to the total atmospheric burden for some highly persistent compounds<sup>(2)</sup>. The complexities of source identification are further compounded by the fact that pesticides that have been banned or severely restricted in North America are still being used in other parts of the globe: through long-range atmospheric transport, some of these toxics are still impacting the Great Lakes environment. While the locations of pesticide usage together with an analysis of the physical-chemical properties of pesticides can provide qualitative estimates of the potential for local, regional and global sources to impact the Great Lakes, quantitative source attribution on which to base policy decisions will likely rely heavily on the use of theoretical

models of the emission to air, atmospheric transport and transformation, and the exchange with the water surfaces.

Options for managing the deposition of pesticides to the Great Lakes are few and are mainly directed toward controlling emission sources through banning of the use of persistent pesticides or through restrictions on their use and method of application. The objective of this paper is to address pesticide emissions to the atmosphere resulting from different methods of application and the impact of subsequent tilling of the soil. Such emissions data are essential inputs to transport and deposition models that are used to quantify the impacts on critical receptors such as the Great Lakes. For the study, the Pesticide Emissions Model (PEM)<sup>(3)</sup> has been used to compare the emission over a three year period, of twenty pesticides following direct application to soil through either incorporation into the soil, surface spraying or in-furrow application at the time of planting. The impacts of annual tilling in the spring or fall as well as the benefits of no tilling are also compared. Several of the restricted or banned Level I and II pesticides of concern listed in the U.S. – Canada Great Lakes Binational Toxics Strategy (GLBTS) have been included to address the continued use of these substances elsewhere on the globe.

## PESTICIDE EMISSIONS MODEL DESCRIPTION

PEM is a numerical model which solves for the advection and diffusion of heat, moisture and pesticide concentration in agricultural soils in either the presence or absence of a crop canopy. The model is driven by hourly meteorological data available from climate observing stations or from meteorological models. Figure 1 shows the main modules of the pesticide emission model as well as the input data requirements. Horizontal diffusion and advection are neglected in the soil column which is divided into 45 variable spaced levels over a 1 m soil depth with the greatest resolution near the soil surface. The relatively large number of levels in the PEM is required to properly define the pesticide concentration profile in the soil for computing the volatilization rate. The time dependent one-dimensional governing equations for heat, moisture and pesticide concentration are solved using a finite element technique with a time step of 1200 seconds.

At the surface, PEM is coupled to the atmospheric surface layer through a surface energy balance. The sensible and latent heat fluxes are modeled using similarity theory for the atmospheric surface layer while the radiative heat fluxes are modeled using a simple radiation model which employs the incoming solar radiation at the ground surface. Soil moisture and heat fluxes at the surface are modeled by PEM. A comparison of modeled and measured volatilization fluxes from bare soils for spray applied triallate and trifluralin has been conducted and shows good agreement between the field data and model estimates over a five day period following the pesticide application<sup>(4)</sup>. PEM is also coupled to a modified 'big leaf' canopy sub-model which includes interception of post-emergent spray by the canopy as well as the subsequent volatilization and/or wash off during precipitation events. Complete details of the pesticide emission model can be found in Scholtz *et al.*<sup>(3)</sup>.

To provide a perspective on the application of PEM as a module of the modeling of transport and deposition Figure 2 is given as an example of the atrazine emissions generated using PEM for the Lake Michigan Mass Balance (LMMB) study<sup>(5)</sup>. Hourly emissions of atrazine resulting from pre- and post-emergent spray applications to mainly sorghum and corn for input to the U.S. EPA Community Multiscale Air Quality (CMAQ) model were modeled using PEM for the period April through July 1995 and for the geographic domain shown in Figure 2. The Mesoscale Meteorological Model (MM5-PX) was used to provide gridded meteorology to PEM. Modeled atrazine emissions were found to be strongly dependent on the evaporation of moisture which draws water from the deeper soil bringing atrazine to the surface where it volatilizes. Figure 2 shows emissions near the peak of the diurnal cycle on June 7 at 14:00EST and the highest emissions are seen in the corn and sorghum growing areas to the southwest of Lake Michigan.

## STUDY METHODOLOGY

### Pesticide Application

PEM has been implemented to simulate three methods of pre-emergent pesticide application: soil incorporation uniformly into the top 10 cm of soil, spray application onto the soil surface and application of pesticide in the bottom of a 10 cm deep furrow which is then covered over, effectively isolating the pesticide from the atmosphere. Soil organic carbon content was assumed to be 1.25% and the soil texture class used was sandy-clay-loam with hydraulic properties taken from Clapp and Hornberger<sup>(6)</sup>. Twenty pesticides, applied by all three methods, were selected to represent a range of pesticide properties rather than for their actual method of application. Clearly the herbicides included in the study would not in reality be applied in-furrow at the time of planting, however, it is emphasized that the focus of this study is on comparisons for a range of pesticide properties rather than on actual named pesticides.

### Pesticide Properties

The physical-chemical properties used to represent the pesticides are listed in Table 1<sup>(7)</sup>. The inclusion of several banned or restricted Level I and II GLBTS pesticides provides information on emission resulting from use outside of Canada and the U.S. while the results for soil incorporation can also be applied to soil residue emissions due to historical use in North America. The temperature dependence of the Henry's Law coefficient was calculated using a latent heat of vaporization of 50 kJ/mole for all pesticides.

### Meteorological data

For the present study, hourly 1989 surface weather observations from a climate station in Indianapolis, Indiana were used to drive PEM and were assumed to be representative of typical North American agricultural areas. The 1989 meteorology record was repeated in sequence for four years to simulate a multi-year period. Figures 3 and 4 show the annual cycles of soil surface temperature and moisture predicted by PEM over the years 2 – 4. After initializing the model in year 1, the variation of soil heat and moisture is independent of the number of years of integration.

### Timing of Application and Tilling

During the first year of model integration, only the soil heat and moisture modules were iterated to initialize the soil temperature and moisture profiles. Pesticides were applied once in the second year and the resulting hourly emissions were predicted by PEM up until the end of the fourth year. Pre-emergent pesticide application was assumed to occur on Julian day 132, which is 15 days after the last occurrence of frost. Spring and fall tilling were assumed to occur on the last and first days of frost occurrence (Julian days 117 and 288, respectively). Since the soil model equations are linear, the application rate was arbitrarily set a  $1 \text{ kg}\cdot\text{ha}^{-1}$  with all emissions expressed as a percentage of the applied pesticide. Direct emissions to the air due to spray droplet drift are not considered in this study.

## RESULTS

The first parts of this section present PEM model results over a three year period for the daily average percentages of applied pesticide that are lost to the atmosphere when applied through soil incorporation, surface spray or, covered over in a furrow. The final part gives results for the total percentages lost over a period of three years following application.

## Daily Average Percentage Loss of Applied Pesticides

Space does not permit daily average emission plots for all pesticides to be included in this paper. Instead, several examples have been selected to illustrate some of the more important findings of the study. Again, it should be noted that while the pesticides are discussed by name, the emphasis is intended to be on the properties representing the pesticides rather than on the pesticides themselves for which certain application methods would be inappropriate.

### Soil incorporated pesticide:

Figures 5 (no tilling), 6 (fall tilling) and 7 (spring tilling) show plots of the daily average percentage loss to the atmosphere of the persistent pesticide chlordane when it is applied by incorporation into the top 10 cm of the soil, 15 days after the last frost (day 132). Without tilling, once the initial near-surface solute has been depleted through loss to the atmosphere, the strong binding of chlordane to the soil carbon ( $K_{oc} = 20 \text{ m}^3 \cdot \text{kg}^{-1}$ ) restricts its movement to the soil surface and emissions in the second and third years after application are some 40 times less than the peak at application. When the soil is tilled on day 288 in the fall (Figure 6) or on day 117 in the spring (Figure 7), however, chlordane from beneath the surface is newly exposed to the atmosphere and episodes of emission characterized by the sharp peaks in these two figures occur. The decline in the subsequent year's emission peaks is partly due to degradation in the soil with a half-life of 1205 days but the leaching of solute to below the 10 cm tilling depth can also reduce the emission on subsequent years. In Figure 7, it is noted that the spring tilling peak is actually higher than the initial peak at application. Two factors account for the higher peak; firstly the temperature at tilling on day 117 is  $20.8^\circ\text{C}$  compared to  $13.9^\circ\text{C}$  at incorporation on day 132 leading to both a higher Henry's law coefficient and secondly, a higher rate of evaporation from the moist soil in the spring which brings dissolved chlordane to the surface. At the time of fall tilling on day 288, the surface temperature is  $21.1^\circ\text{C}$  and the soil is dryer than in the spring. This is contrasted by the behavior shown in Figure 8 which is a plot of the daily average percentage loss of applied atrazine when it is incorporated into the top 10 cm of the soil which is then tilled in the fall on day 288. When this plot is compared with the results for atrazine incorporation but without subsequent tilling of the soil (not shown), it is found that fall tilling of the soil has essentially no effect on the atrazine emissions. Atrazine has a high solubility ( $1.07 \text{ kg} \cdot \text{m}^{-3}$ ), low soil sorption ( $K_{oc}=0.1 \text{ m}^3 \cdot \text{kg}^{-1}$ ) and a relatively short degradation half-life in the soil of 60 days; as a consequence, the atrazine in the top 10 cm of soil is rapidly depleted through decay and leaching into the deeper soil layers.

### Sprayed Pesticide

Figure 9 shows the percentage of atrazine lost to the atmosphere when it is applied to the soil as a surface spray. The peak percentage lost in this case is some 2.8 times the peak loss with soil incorporation (Figure 8, for example). Figures 10 (no tilling) and 11 (fall tilling) show the daily average percentage losses of a persistent pesticide (degradation half-life in soil of 1 year) with properties similar to those of toxaphene, when applied to the soil as a pre-emergent spray. Toxaphene is very strongly bound in the soil ( $K_{oc} = 100 \text{ m}^3 \cdot \text{kg}^{-1}$ ) and as a consequence if the soil is not tilled, it remains close to the soil surface and emissions that are supported by diffusion persist into the second and third years after application. If the soil is tilled in the fall (Figure 11), however, the near-surface toxaphene is mixed into the top 10 cm soil depth which reduces the subsequent daily loss to the atmosphere by a factor of approximately ten. The toxaphene peak daily emission is 1.55% of applied material compared to 0.27% per day for atrazine; the higher toxaphene loss is due to its relatively high Henry's law coefficient ( $K_H = 1.7 \times 10^{-4}$ ) compared to that of atrazine ( $1.19 \times 10^{-7}$ ). In contrast, Figure 12 for spray applied endosulfan shows a rapid loss of this pesticide to the atmosphere, some 14% in the day of application, due to its high value of  $K_H (=1.22 \times 10^{-3})$ . In total, approximately 70% of the spray-applied endosulfan is lost to the atmosphere in the short period of emission shown in Figure 12. There is virtually no soil residue in the top 10 cm of the soil by the fall and tilling of the soil does not increase the total loss to the atmosphere.

### Pesticide applied in-furrow

Figures 13 (no tilling) and 4.10 (fall tilling) show the effects of tilling on endosulfan loss to the atmosphere when it is applied to the soil in a furrow and covered over. In the absence of tilling, the strong soil sorption of endosulfan ( $K_{oc}=124 \text{ m}^3.\text{kg}^{-1}$ ) greatly restricts its mobility in the soil and essentially no endosulfan is lost to the atmosphere over a three year period and with its degradation half-life in soil of 50 days, virtually no soil residue persists after a three year period. On the other hand, if the soil is tilled in the fall (Figure 14), approximately 90% of the endosulfan has degraded in the soil and the peak daily loss rate is only some 0.08% of the applied pesticide.

Figures 15 (no tilling) 16 (fall tilling) and 17 (spring tilling) show PEM model results for the percentages of lindane ( $\gamma$ -hexachlorocyclohexane) lost to the atmosphere when applied in the form of lindane treated seed, a common mode of application for wheat planting. Lindane is relatively water soluble ( $0.055 \times 10^{-1} \text{ kg.m}^{-3}$ ) and relatively loosely bound to the soil carbon ( $K_{oc}=1.1 \text{ m}^3.\text{kg}^{-1}$ ) and even without tilling, it is able to reach the soil surface in significant concentrations as the soil dries in the summer season resulting in an annual maximum daily loss rate to the atmosphere. Tilling of the soil in fall or spring exposes the residual lindane in the deeper soil to the atmosphere, increasing the peak emissions by as much as a factor of five. Without any tilling of the soil, while the soluble lindane can reach the surface, its relatively low  $K_H$  ( $5.30 \times 10^{-5}$ ) limits its loss to the atmosphere and lindane tends to accumulate at the soil surface during periods of soil drying, hence, the slightly higher peak (0.13% loss per day) in the second year after application compared to 0.115% in the first year (Figure 15). Figure 18 shows the daily loss of the toxic isomer,  $\alpha$ -hexachlorocyclohexane, for in-furrow application and a spring till. The peak of the emission episode that accompanies the spring tilling of the  $\alpha$ -isomer (6.9%) is approximately twice the magnitude of that for tilling of the  $\gamma$ -isomer (3.2%) which has a much lower  $K_H$  ( $5.30 \times 10^{-5}$ ) than the  $\alpha$ -isomer ( $3.57 \times 10^{-4}$ ).

### **Effects of Pesticide Application Method on Total Three Year Loss to the Atmosphere**

Figures 19, 20 and 21 are bar charts that compare the total pesticide losses to the atmosphere over a three year period following three different methods of application and with or without soil tilling in the fall or spring. The label numbers associated with each bar group identify the pesticide properties that were used from Table 1. It is immediately apparent from these three figures that for the range of pesticide properties studied, in-furrow application, with or without subsequent tilling, results in the lowest total percentage loss of applied pesticide to the atmosphere. As might be expected, spray application results in the highest losses, with in excess of 80% lost to the atmosphere for seven of the twenty pesticides considered in this study (Figure 20). Some herbicides, however, such as 2,4-DB (#1), atrazine (#3), metolachlor (#15) and metribuzin (#16) are less sensitive to the application method with losses of less than 25%. As can be noted from Figure 20, losses following spray application are not much influenced by tilling practices. For several pesticides, including toxaphene which has already been discussed above, tilling in the fall rather than the spring, slightly reduces the total percentage of sprayed pesticide lost to the atmosphere by mixing near surface material into the deeper soil at the first fall tilling day. In all cases, losses of spray applied pesticide are the highest without any tilling of the soil. Tilling has the largest impact on in-furrow applications by exposing buried pesticide to the air (Figure 21). Losses of the least mobile pesticides in the soil, those with  $K_{oc} > 10 \text{ m}^3.\text{kg}^{-1}$ , are increased the most by tilling the soil; the more mobile pesticides are more able to move to the surface dissolved in the interstitial water as the soil dries during the summer months. The percentage losses in Figure 19 for soil incorporated pesticides are larger than those for in-furrow application but still much less than the losses for spray application. With soil incorporation pesticide is exposed to the atmosphere from the time of application whereas with in-furrow application only when pesticide is brought to the surface through evaporation of water or through tilling do emissions to the air become significant. As a

consequence, there is less of an impact on the emissions for incorporated pesticides when the soil is tilled when compared to results for untilled soil.

The following table summarizes the rankings of pesticide losses to the atmosphere that result from the range of pesticide properties studied and the different methods of application and tilling practices.

Application of Tilling Practice	Number of pesticides with total loss over three years of:					
	0 – 5%	5 – 10%	10 – 20%	20 – 50%	50 - 75%	75 – 100%
in-furrow						
• no tilling	16	2	2	0	0	0
• fall tilling	10	3	4	3	0	0
• spring tilling	11	4	4	1	0	0
incorporation						
• no tilling	7	3	5	5	0	0
• fall tilling	4	5	5	6	0	0
• spring tilling	5	5	4	6	0	0
surface spray						
• no tilling	1	2	0	2	7	8
• fall tilling	1	2	0	5	5	7
• spring tilling	1	2	0	4	6	7

From this table it is seen that surface spraying results in more than 50% loss of applied pesticide to the atmosphere for between 12 and 15 of the pesticide properties studied; seven of the pesticides in this group have losses in excess of 85%. This is contrasted with soil incorporation and in-furrow application that have no losses in excess of 50%.

### Uncertainty in the Results

There are two aspects to the uncertainty in the findings presented in this paper; the first is the uncertainty in the predicted percentages of the pesticide loss modeled by PEM; the second is uncertainty in the relative magnitudes of the modelled losses using different application methods and tilling practices. The uncertainty in the predicted percentages lost is much larger than that for the comparisons made between the magnitudes of the percentages. While PEM is believed to include the most significant physical processes that determine the emissions, there are many aspects to the partitioning and degradation in the soil, such as pH, the presence of other ions and solutes, and chemical and biochemical reaction rates, that are not well understood but will have significant influences on the magnitudes of the losses to the atmosphere for a given set of physical-chemical properties. Comparisons between the magnitudes of the loss for different agricultural practices, however, are expected to have a relatively low level of uncertainty since the uncertainty in the soil partitioning and degradation would likely effect the different application and tilling methods in a similar manner.

### CONCLUSIONS

A pesticide emission model (PEM) has been used to assess the impact of agricultural practices on the total percentage of pesticide applied to the soil that is lost to the atmosphere over a three-year period. Emissions of twenty pesticides were modeled representing a wide range of physical-chemical properties. The following conclusions result from this modeling study:

If it is appropriate to apply a pesticide in a furrow that is then covered over, this method of application results in the least loss (<26%) of applied pesticide to the atmosphere. The second preferred

method of application is soil incorporation (<44%) while the highest losses of applied pesticide to the atmosphere (up to 92%) result when pesticide is applied to the soil as a pre-emergent spray.

Subsequent tilling of the soil leads to a large increase in the percentage lost for in-furrow applications of persistent pesticides that are strongly sorbed to the soil carbon. Smaller, but still significant increases, result on subsequent tilling of soil incorporated pesticides. Fall tilling of soil onto which pesticide has been sprayed has little effect for most pesticides properties studied but for a small number of strongly sorbed pesticides tilling of the soil in the fall results in decreases of up to 30% in the total loss to the atmosphere with smaller decreases for spring tilling in the following year.

## ACKNOWLEDGEMENTS

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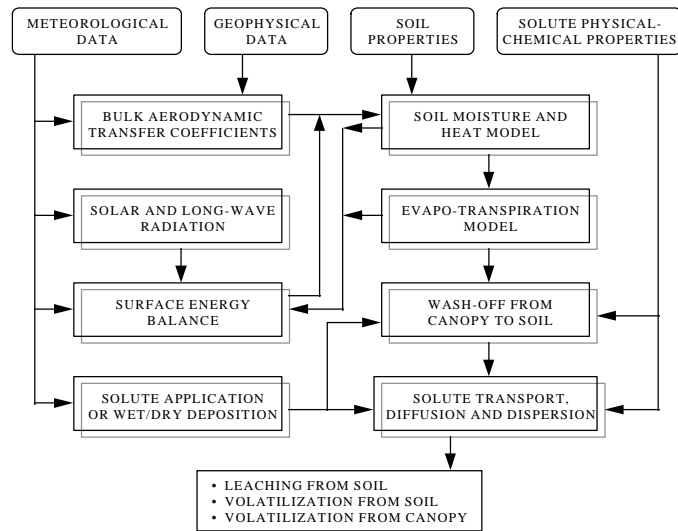
**Table 1: Physical-Chemical Properties of Pesticides<sup>(7)</sup>**

#	Pesticide	Class*	Diffusivity in Air (m <sup>2</sup> /s)	Diffusivity in Water (m <sup>2</sup> /s)	K <sub>oc</sub> – Soil Sorption (m <sup>3</sup> /kg)	K <sub>H</sub> – Henry's Law Constant (dim'less)	Soil Half Life (days)
1	2,4-DB	H	4.97 x 10 <sup>-6</sup>	4.97 x 10 <sup>-10</sup>	0.5	2.36 x 10 <sup>-7</sup>	7
2	Aldrin	I	4.97 x 10 <sup>-6</sup>	4.68 x 10 <sup>-10</sup>	5.01	3.74 x 10 <sup>-2</sup>	53
3	Atrazine	H	4.97 x 10 <sup>-6</sup>	5.39 x 10 <sup>-10</sup>	0.1	1.19 x 10 <sup>-7</sup>	60
4	Chlordane	I	4.97 x 10 <sup>-6</sup>	4.51 x 10 <sup>-10</sup>	20	3.70 x 10 <sup>-3</sup>	1205
5	DDT	I	4.47 x 10 <sup>-6</sup>	4.54 x 10 <sup>-10</sup>	411	9.69 x 10 <sup>-4</sup>	1095
6	Dieldrin	I	4.97 x 10 <sup>-6</sup>	4.67 x 10 <sup>-10</sup>	12	4.60 x 10 <sup>-4</sup>	2555
7	Endosulfan	I	4.57 x 10 <sup>-6</sup>	4.72 x 10 <sup>-10</sup>	12.4	1.22 x 10 <sup>-3</sup>	50
8	Endrin	I	4.97 x 10 <sup>-6</sup>	4.67 x 10 <sup>-10</sup>	10	1.35 x 10 <sup>-5</sup>	1825
9	Fenthion	I	4.97 x 10 <sup>-6</sup>	5.21 x 10 <sup>-10</sup>	1.5	9.03 x 10 <sup>-6</sup>	34
10	a-HCH	I	5.41 x 10 <sup>-6</sup>	5.48 x 10 <sup>-10</sup>	2.59	3.57 x 10 <sup>-4</sup>	400
11	Heptachlor	I	4.97 x 10 <sup>-6</sup>	4.76 x 10 <sup>-10</sup>	24	4.60 x 10 <sup>-2</sup>	219
12	Hexachlorobenzene	F	5.56 x 10 <sup>-6</sup>	5.81 x 10 <sup>-10</sup>	411	2.92 x 10 <sup>-3</sup>	365
13	Lindane	I	5.18 x 10 <sup>-6</sup>	5.48 x 10 <sup>-10</sup>	1.1	5.30x 10 <sup>-5</sup>	400
14	Methoxychlor	I	4.97 x 10 <sup>-6</sup>	4.97 x 10 <sup>-10</sup>	79.4	4.10 x 10 <sup>-4</sup>	120
15	Metolachlor	H	4.51 x 10 <sup>-6</sup>	4.97 x 10 <sup>-10</sup>	0.2	9.10 x 10 <sup>-7</sup>	90
16	Metribuzin	H	5.79 x 10 <sup>-6</sup>	4.97 x 10 <sup>-10</sup>	0.06	9.30 x 10 <sup>-8</sup>	40
17	Mirex	I	4.97 x 10 <sup>-6</sup>	4.05 x 10 <sup>-10</sup>	3260	3.45 x 10 <sup>-1</sup>	365
18	Quintozene (PCNB)	F	5.59 x 10 <sup>-6</sup>	4.97 x 10 <sup>-10</sup>	5	4.1 x 10 <sup>-5</sup>	250
19	Toxaphene	I	4.97 x 10 <sup>-6</sup>	4.35 x 10 <sup>-10</sup>	100	1.70 x 10 <sup>-4</sup>	365
20	Triallate	H	4.67 x 10 <sup>-6</sup>	4.71 x 10 <sup>-10</sup>	2.4	4.19 x 10 <sup>-4</sup>	82

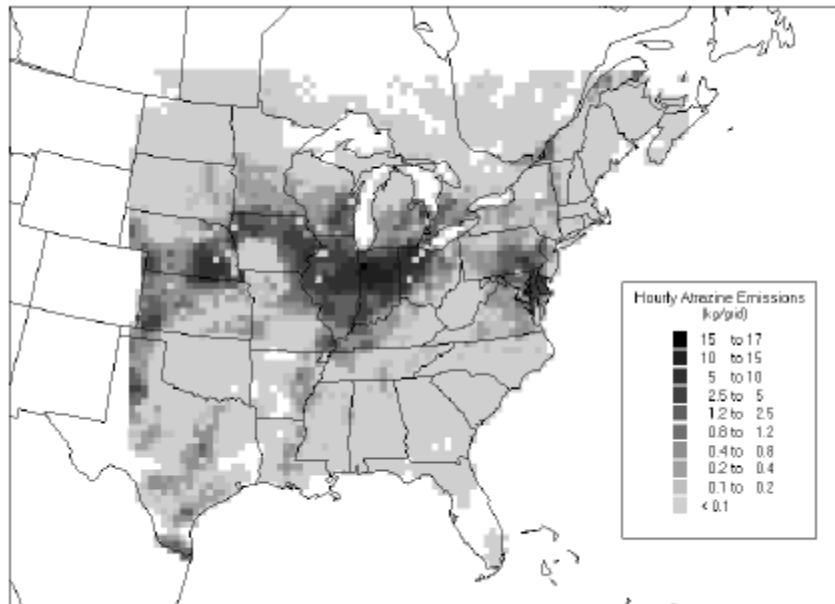
\* H – herbicide; I – insecticide; F – fumigant



**Figure 1: Summary of inputs, outputs and main modules of PEM**



**Figure 2: Hourly atrazine emissions for Julian day 158, 19:00 GMT (14:00 EST)<sup>(5)</sup>**



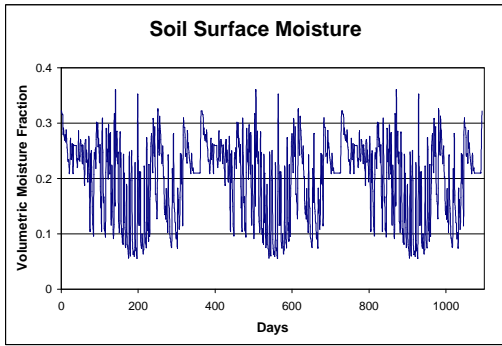


Figure 3: Modeled Soil Surface Moisture

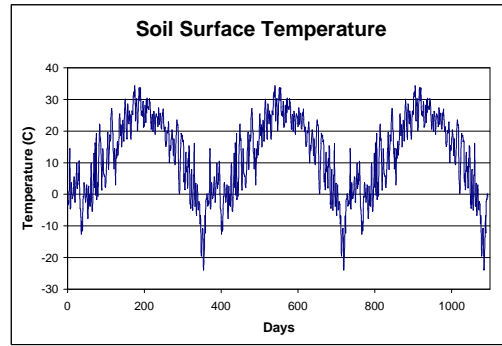


Figure 4: Modeled Soil Surface Temperature

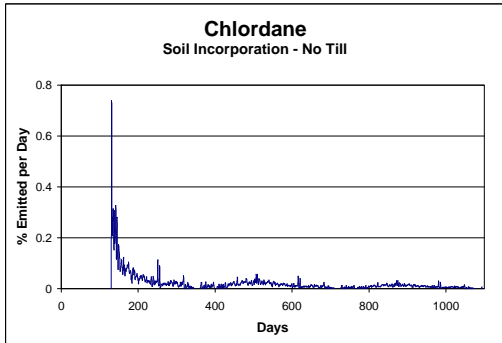


Figure 5: Soil Incorporation, No Till

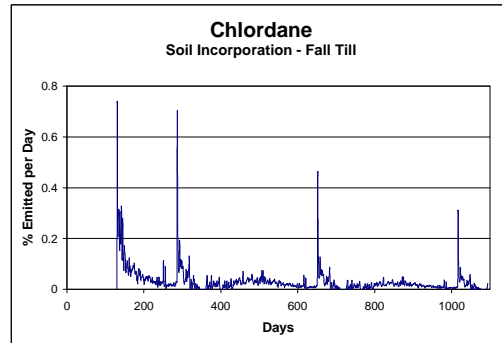


Figure 6: Soil Incorporation, Fall Till

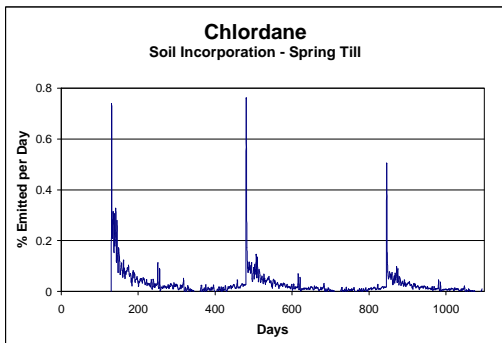


Figure 7: Soil Incorporation, Spring Till

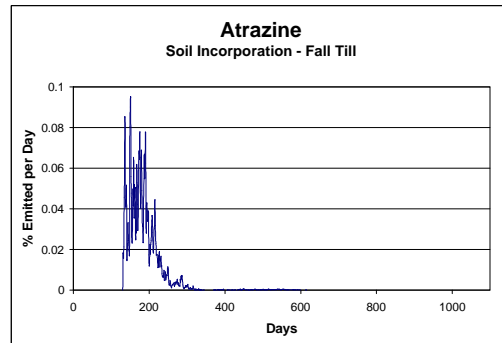


Figure 8: Soil Incorporation, Fall Till

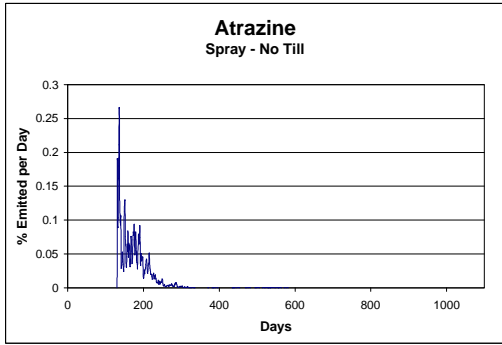


Figure 9: Spray Application, No Till

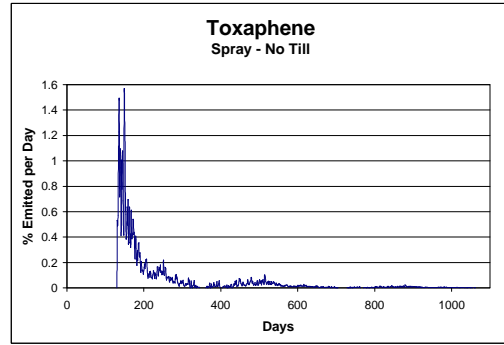


Figure 10: Spray Application, No Till

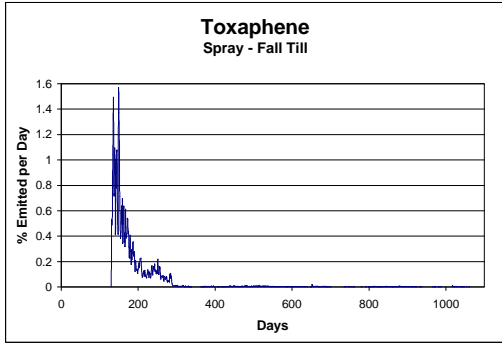


Figure 11: Spray Application, Fall Till

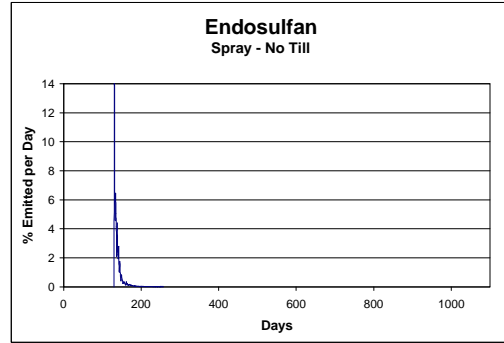


Figure 12: Spray Application, No Till

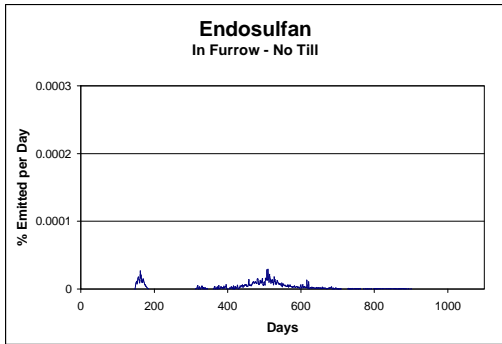


Figure 13: In-Furrow Application, No Till

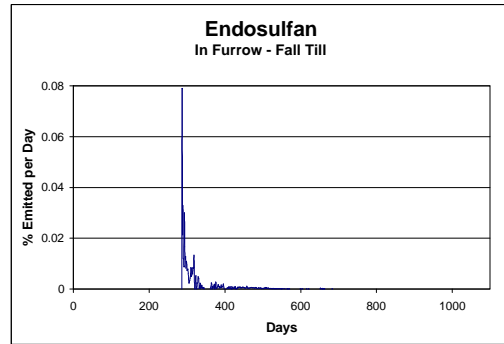


Figure 14: In-Furrow Application, Fall Till

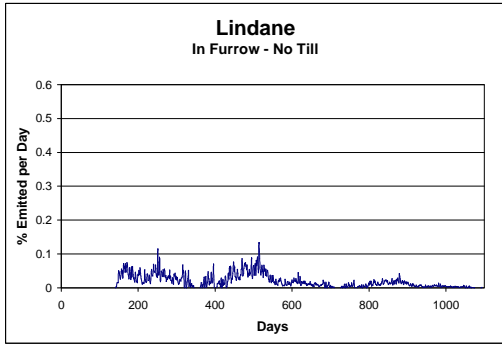


Figure 15: In-Furrow Application, No Till

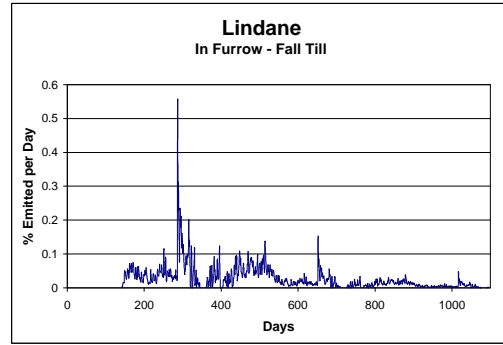


Figure 16: In-Furrow Application, Fall Till

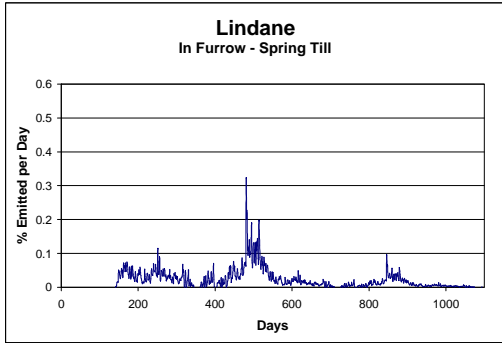


Figure 17: In-Furrow Application, Spring Till

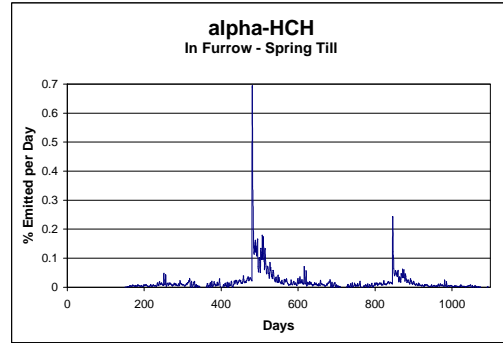


Figure 18: In-Furrow Application, Spring Till

### Soil Incorporation

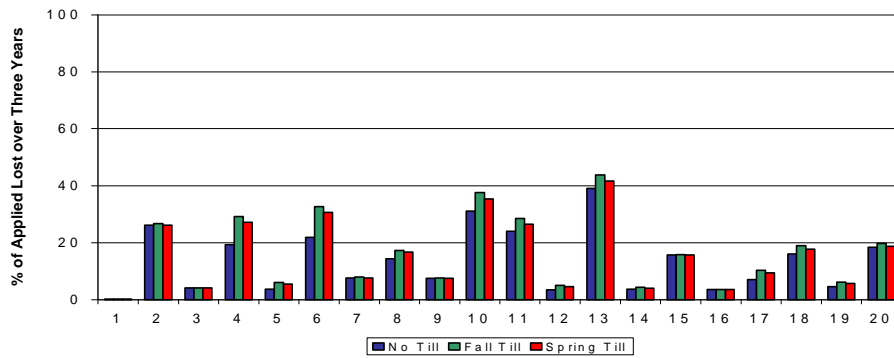
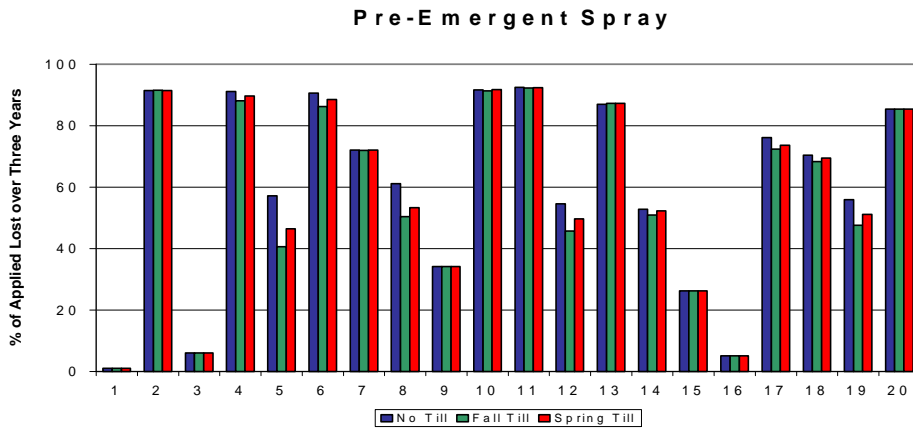
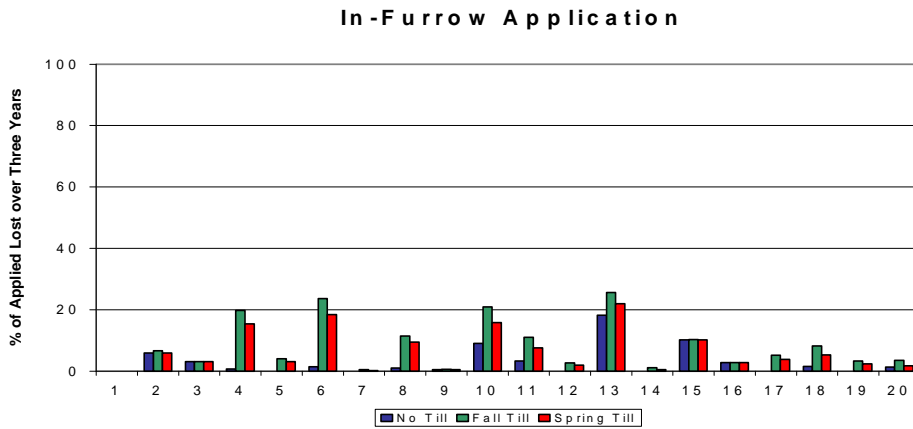


Figure 19: Soil Incorporation - Effect of Tilling Practice on Pesticide Emissions (bars are in same order as the legend)





**Figure 20: Pre-emergent Spray Application – Effect of Tilling Practice on Pesticide Emissions (bars are in the same order as the legend)**



**Figure 21: In-Furrow Application – Effect of Tilling Practice on Pesticide Emissions (bars are in the same order as the legend)**

## **KEYWORDS**

Emission Inventories  
Pesticides  
Agricultural practices  
Soil Model