Modeling Pesticide Volatilization From Turf

How much pesticide is lost as fumes and vapors from treated turf?

BY DOUGLAS A. HAITH

Using an air sampler to collect vapors from evaporated pesticides, researchers evaluate how environmental conditions impact pesticide evaporation loss.

Control of turf pests has to be one of the least attractive and most worrisome aspects of turf management. While the use of chemical pesticides is generally considered necessary to maintain high turf quality, those same toxic properties that provide pest control may be hazardous to ecosystems and human health. Pest management is a balance between healthy, functional turf and a safe, sustainable environment. The way out of this challenging situation is through the use of *best management practices* that not only limit pest damage, but also have minimal environmental risk.

The search for such control options is a major goal of researchers, managers, and many others in the turf industry. A key requirement for this work is the ability to predict what happens to pesti-

cides after their application to the turf. Are the chemicals taken up by the grass? Do they dissolve and leach into the soil and move to groundwater? Are they washed away in runoff to streams and ponds? Do they vaporize and are the fumes breathed by golfers and others? With such knowledge, we can identify chemicals and application methods that minimize the risk to both the environment and to human health.

The most useful tools for predicting chemical behaviors in the environment are "fate and transport" models. These are mathematical equations of chemical transformations and transport that are converted into computer programs that can be run for any chemical or site of interest. The software user typically provides input data, including weather records, chemical properties, and site characteristics, and the program calculates disposition of the chemical. Fate and transport models are routinely used in assessment of air pollution from combustion emissions (e.g., power plants and automobiles) and water pollution from municipal and industrial wastes, as well as for chemicals applied to agricultural crops. The approach has seldom been applied to turf, however, mainly due to a lack of suitable models.

The USGA Turfgrass and Environmental Research Program has sponsored research at Cornell on fate and transport modeling for turf systems for the past several years. A recent *Green Section Record* article (March/April 2002)

described the successful development of a pesticide runoff model that is now being distributed to consultants and other turf professionals. This article describes a companion project dealing with volatilization of turf pesticides. The primary goal is the development and testing of a fate and transport model that can be used to predict the amounts of a pesticide that will volatilize from turf under various site and weather conditions. Another goal of the project is to determine the likely effects of those vapors on human health.

PREDICTING PESTICIDE VOLATILIZATION

The physics of volatilization are well understood. Molecules of a substance escape as a gas, typically from a liquid, when sufficient energy is provided. The gas accumulates above the liquid surface, and, in the absence of air movement, eventually saturates the air, limiting further vaporization. In the case of pesticides, however, several factors complicate this simple picture. Pesticide vapors may be transported away from the ground surface by moving air, thus encouraging more volatilization. Pesticides on the grass and thatch may be in solid or liquid form. Portions of the chemicals may be adsorbed by thatch and grass organic matter. Biological and chemical degradation may also occur.

Even considering these complicating factors, there is a volatilization process with which we are very familiar. That

Figure 1
**Comparison of Modeled and Measured
Pesticide Volatilization for Each Experiment**
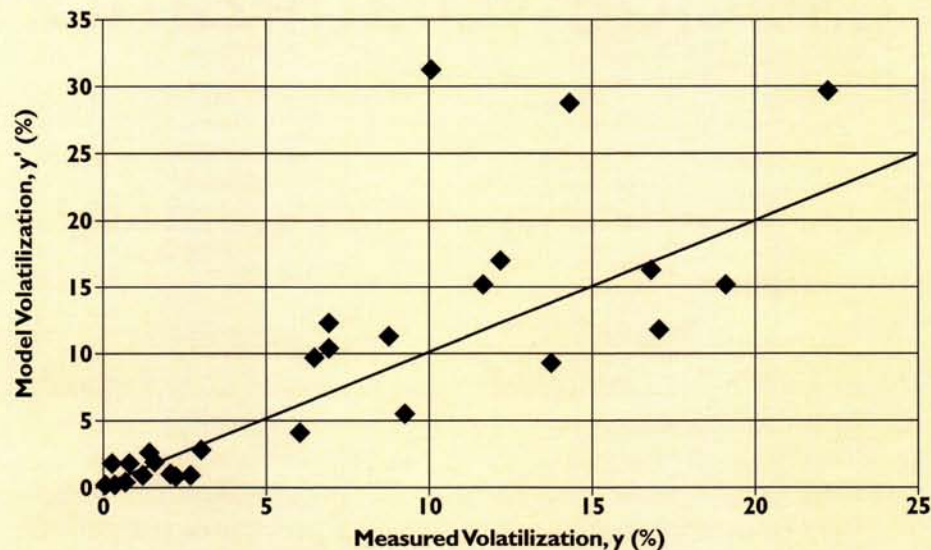
involves the loss of water vapor from turf through evapotranspiration (ET). Pesticide volatilization is governed by the same processes that affect water evaporation. So factors such as air temperature, solar radiation, and wind movement can be expected to have comparable effects on vaporization of both water and pesticides. Models for estimating ET from turfgrass are readily available. It is reasonable that evaporation values from such models could be converted to pesticide vaporization by scaling factors that reflect the differences in chemical properties of water and pesticide.

This hypothesis was tested by constructing a simple volatilization model that first computed hourly ET using a modified Penman equation. These water values were then adjusted using two chemical properties, vapor pressure and latent heat of vaporization of the water and the pesticide. The model also calculated a simple mass balance of pesticide on the turf vegetation. We did not distinguish between pesticides that were dissolved or in solid form. All were assumed as potentially volatile.

The model was tested using data from field turf experiments conducted

at the University of Massachusetts's Turfgrass Research Center in South Deerfield. The plots had well established creeping bentgrass maintained at a half-inch mowing height. Thatch thickness ranged from about 0.4" to 0.6". The soil was a Hadley silt loam. Irrigation was applied as necessary to prevent drought stress.

Testing data included the measured concentrations of volatile residues following application of pesticides in 11 experiments conducted in the 1995-97 growing seasons. Pesticides were applied at the beginning of each experiment,

and volatile residues were collected during sampling intervals of one to four hours between 8:00 AM and 7:00 PM.

PREDICTED VERSUS MEASURED

The experimental measured volatilization values are compared with model predictions for six chemicals in Figure 1. Each data point in the figure corresponds to the model prediction and measured pesticide volatilization for an experiment. Points lying on the line y' = y represent perfect model performance. In other words, model values are exactly equal to observations. Points above the line indicate over-prediction by the model where predicted pesticide volatilization is higher than the measured value. Events lying under the line are under-predicted. Most results fall relatively close to the line of perfect prediction (y' = y), although in three of the ethoprop experiments, model predictions were much too high.

Table 1 compares the predictions and measurements for each pesticide. In general, it is encouraging that the model appears to be most applicable to those chemicals that have the largest volatilization losses (diazinon, ethoprop, chlorpyrifos). This conclusion is qualified somewhat by the substantial over-prediction of ethoprop vaporization. The results were also relatively good for the two chemicals with moderate vola-

Table 1
Comparison of Modeled and Measured Pesticide Volatilization

Pesticide	Number of Experiments	Mean Volatilization (% of applied)	
		Model	Measured
Bendiocarb	4	1.63	1.74
Carbaryl	4	0.07	0.28
Chlorpyrifos	4	8.16	8.25
Diazinon	4	10.04	10.46
Ethoprop	7	21.82	15.15
Isofenphos	6	0.97	1.53
Mean (all events)		8.23	6.82

tilization, bendiocarb (1.63%) and isofenphos (1.53%), although the predicted isofenphos mean was only 63% of the observed value. The only severe error was for carbaryl. However, given the very low measured values (0.28%), it is difficult to give much significance to this error. Based on these results, we are confident that an ET-based approach is a reasonable way to estimate pesticide volatilization from turf.

PREDICTION OF HEALTH HAZARDS FROM PESTICIDE VAPORS

The health impact of inhaled pesticide vapors can be described through the concept of a hazard quotient (HQ). The HQ is the estimated inhaled dose for a 70 kg (154 lb.) adult divided by the "chronic reference dose" (Rfd) for the chemical. The Rfd is the level of a chemical in the body which is likely to cause chronic health problems. Pesticide concentrations that produce an HQ greater than "1" are potentially unsafe or hazardous. Thus, given reliable estimates of vapor concentrations, we can relate them directly to human health hazards. The challenge has been to obtain these estimates of vapor concentrations.

One approach is to relate pesticide concentrations in the air above the turf to simple chemical properties, such as vapor pressure. Figure 2 shows the relationship between maximum air concentration and vapor pressure for the pesticides used in the experiments in the previous section. It is apparent that chemicals with the highest vapor pressures also have the highest air concentrations. We used the relationship in Figure 2 to estimate maximum vapor concentrations and associated inhalation hazard quotients (HQs) for eight pesticides included in the Massachusetts experiments. HQs were also calculated using the measured concentrations, and the two sets are compared in Table 2.

Although the vapor pressure relationship results in HQ values that are different from measured values, the differences are not large enough to produce

misleading conclusions regarding hazards. The estimated concentrations clearly identify the same hazardous chemicals (HQ > 1) as would be flagged by the measured concentrations. Diazinon, ethoprop, and isazofos appear to have clear volatilization hazards, but bendiocarb, carbaryl, chlorpyrifos, and isofenphos are relatively benign.

In conclusion, this work demonstrates that using an ET-based model to predict

volatilization losses of turfgrass pesticides is feasible. It also demonstrates that by using a simple chemical property, such as vapor pressure, hazard quotients can be estimated for turfgrass pesticides that accurately rank their health hazards.

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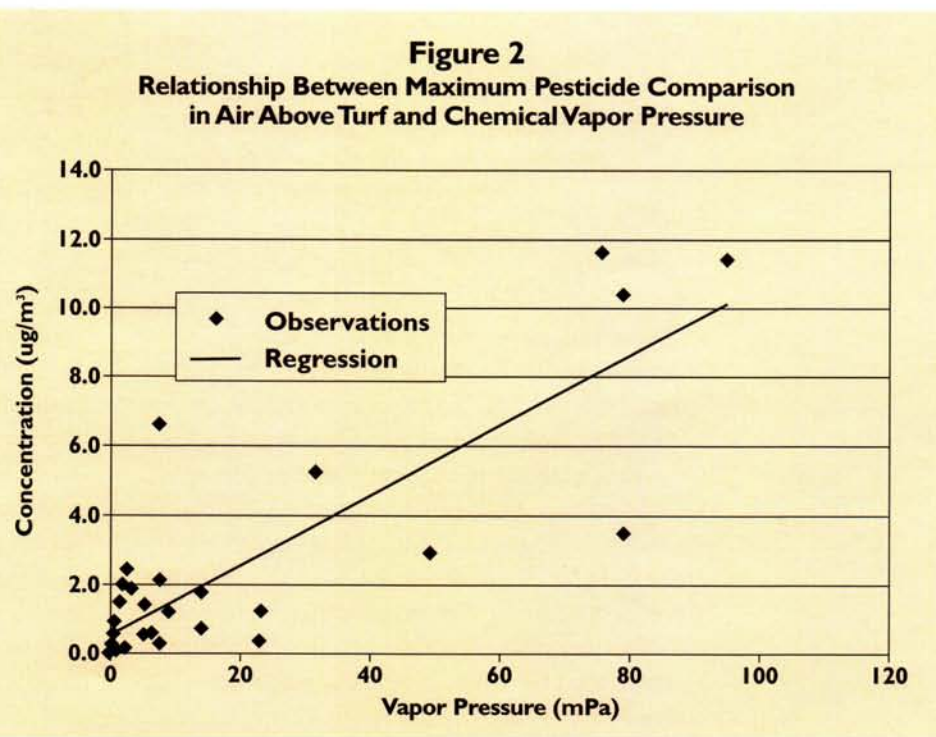

Figure 2
Relationship Between Maximum Pesticide Comparison in Air Above Turf and Chemical Vapor Pressure

Table 2
Comparison of Volatilization Hazard Quotients (HQs) Based on Measured Pesticide Concentrations and Concentrations Predicted from the Vapor Pressure Relationship in Figure 2

Chemical	Hazard Quotient (HQ)	
	Determined from Measured Concentration	Determined from Predicted Concentration
Bendiocarb	0.01	0.03
Carbaryl	0.00	0.01
Chlorpyrifos	0.09	0.04
Diazinon	2.8	2.7
Ethoprop	70.2	61.9
Isazofos	5.2	13.1
Isofenphos	0.12	0.17
Trichlorfon	0.04	0.04