Chapter 1

Research on the Fate of Pesticides Applied to Turfgrass: A Perspective by a Scientist, Administrator and Emeritus

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During the final two decades of the last century, there appeared to be an increasing concern for the potential movement of chemicals from intensively managed turfgrass. Funding opportunities appeared and numerous research programs were initiated across the United States. Results of a research program conducted at the University of Georgia from 1992-1997 indicated that very small fractions of certain pesticides were transported through lysimeters containing the soil mixture recommended by the United States Golf Association for turfgrass maintained as golf course greens. Additionally, small quantities of certain pesticides were transported in surface runoff from treated mini-plots simulating golf course fairways and home lawns. It was concluded that certain pesticides could be applied to turfgrass with minimal risk. Other research programs, conducted during the 1990's, obtained similar results and reached similar conclusions. Did these publicized conclusions result in apathy toward risk assessment research on turfgrass management? It appears that the importance of risk assessment studies on turfgrass management strategies has lessened during recent past. Special funding (eg. grants and gifts) has been reduced considerably over the past five years. Additionally, reduced state and federal budgets have impacted the formula funding at Land Grant Universities (LGU's). Currently in LGU's, use of formula funding for this research suffers compared to other disciplines (eg. genomics, proteomics, and metabolomics). The clientele of these Universities demand research programs

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for improved production and profitability. Administrators of LGU's are faced with tough decisions. The lack of funding sources, the absence of a clientele support, and the apparent apathy toward the data by regulatory agencies create a dilemma for the administrators of LGU's when it comes to utilizing their limited funding for risk assessment programs. Risk assessment/management research programs need: organizations (eg. regulatory agencies) that command their data; a clientele base that depends on the data for the profit margin; and funding agencies.

Introduction

The increasing importance of management practices utilized on golf courses has made it necessary to evaluate the environmental impact of these practices. Generally, perennial grasses have been considered to be a vegetation type that offers stability and preservation to ecosystems. The reduced cultural practices necessary to sustain a perennial crop conserve the soil, compared to the planting and maintenance of an annual crop. The extensive fibrous root system of a perennial grass system increases the soil-water infiltration rate compared to most annual herbaceous crops. Finally, year-long ground cover is usually greater for a grassed area compared to other cropping systems. The benefits of turfgrass as a ground cover, compared to other vegetation types are discussed by Smith (*1, 2*).

The maintenance of a high quality sod for use as golf course greens and fairways requires management strategies that are not always perceived as friendly to the environment. Strategies that include chemical inputs have become a major concern for the press, and ultimately the populace, and these concerns have been translated into the need to develop an acceptable data base to determine the impact of certain golf course management strategies on the environment. Currently, there are more than 16,000 golf courses in the United States. Assuming the average size of 48.6 ha per course, there are nearly 800,000 ha of turfgrass in the golf course industry receiving aggressive management strategies. Nearly 30 million U.S. golfers enjoy these courses and recognize the need for aggressive management systems.

Assuming that 2% of a golf course is managed as putting greens, there are 16,000 ha of greens in the USA that are constructed for maximum infiltration and percolation of water through the rooting media, terminating in a drainage system (e.g. drainage ditch, etc.). Fairways comprise approximately 98% of golf courses and are typically intensively managed, resulting in soil moisture content maintained near field capacity. The fairways are developed on soils typical for each region, and in the Piedmont region, these soils have a high clay content allowing for low water infiltration rates. As much as 70% of a moderate intensity rainfall will occur as overland runoff from the sloped areas typical of the Piedmont region (*3*). This water from the greens and fairways can eventually terminate in potable water containments.

Research Basis for Perspectives

A research program was developed by faculty at the University of Georgia (UGA) to determine the potential fate of pesticides applied to simulated golf course greens and fairways. The objectives of the research program were to evaluate the potential movement of pesticides and fertilizer components following application to golf courses, and to develop Best Management Practices to reduce the potential for analyte transport to potable water systems. The initial steps for evaluating the potential movement of certain pesticides were accomplished using pesticides registered for use on golf courses (Table I) on simulated greens and fairways constructed at the Griffin Campus of UGA (*3*). Simulated greens and fairways were constructed, and pesticide-analytical procedures were developed or improved (*4, 5, 6, 7*) to determine the movement of certain analytes through golf course greens and from golf course fairways.

The construction of golf course greens according to United States Golf Association specifications resulted in rapid infiltration and percolation of water through the rooting medium and out the drain system into surface drainage areas (*8*). At first inspection, these characteristics seemed to allow for the movement of large quantities of pesticides into surface drainage areas. However, our data indicated that the concentrations and quantities of pesticides transported through the simulated greens were very low (Table II). The more water soluble pesticides (eg. 2,4-D; dicamba and mecoprop) were found to have short residence time under the sod. We found that these pesticides were degraded rapidly in the moist high-organic matter media (A. Smith, unpublished). Our data indicated that the half-life for 2,4-D was less than one week at temperatures higher than 17°C (unpublished data). The pesticides with lower water solubilities (eg. dithiopyr, chlorothalonil and chlorpyrifos) had higher soil sorption capacities, increasing their residence time in the rooting medium (because of the sphagnum peat moss component) and allowing for degradation even if the half-lives were longer. This concept was best demonstrated with dithiopyr (*9, 10, 11, 12*).

Table I. Pesticides[§] and Rates Used in This Research

Common Name	*Pesticide Chemical Nomenclature[a]*	*Rate (kg/ha)*
Benefin	*N*-butyl-*N*-ethyl-2,6-dinitro-4-(trifluoromethyl) benzenamine	1.70
2,4-D DMA[b]	(2,4-dichlorophenoxy) acetic acid	2.24
Dicamba DMA	3,6-dichloro-2-methoxybenzoic acid	0.56
Dithiopyr	S,S-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl) -6-(trifluoromethyl)-3,5-pyridinedicarbothioate	0.56
Chlorothalonil	2,4,5,6-tetrachloro-1,3-benzenedicarbonitrile	9.50
Chlorpyrifos	*O,O*-diethyl *O*-(e,5,6-trichloro-2-pyridyl) phosphoro-thioate	1.12
Mecoprop DMA	(±)-2-(4-chloro-2-methylphenoxy) propanoic acid	1.68
Pendimethalin	N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzen amine	1.70

[§] Transport of fertilizer-derived nitrate-N was also monitored
[a] International Union of Pure and Applied Chemistry
[b] DMA = dimethylamine salt formulation

Table II. Pesticide Transported from Field Lysimeters Under Penncross Bentgrass or Tifdwarf Bermudagrass

		Maximum Total Residue Transported Over 70 Days	
Pesticide	*Application Rate kg/ha*	*μg/L*	*% Applied±SE*
2,4-D DMA[a]	0.28	3.2	0.50±0.04
Dicamba DMA[a]	0.07	3.6	0.20±0.16
Mecoprop DMA[a]	0.56	3.8	0.20±0.14
Dithiopyr EC[b]	0.56	2.4	0.49±0.26
Dithiopyr G[c]	0.56	1.7	0.44±0.32
Chlorpyrifos	1.14 (monthly)	7.2	0.01±0.01
Chlorothalonil	9.50 (2x monthly)	2.6	0.01±0.01
OH Chlorothalonil[d]	Not Applicable	160.0	0.10

[a] Dimethylamine salt analyte
[b] Emulsifiable concentration formulation
[c] Granule formulation
[d] Metabolite of chlorothalonil from lysimeters treated with chlorothalonil

Although pesticide metabolites were not routinely analyzed, we chose to determine the transport of the more polar metabolite of chlorothalonil (hydroxychlorothalonil) in effluent from lysimeters treated with chlorothalonil. Data (Table II) indicate that concentrations as high as 160 *u*g L^{-1} were determined in the effluent from the lysimeters treated with chlorothalonil. Similar information is reported by Armbrust (*13*). This is not to imply that this is a concentration of great concern, but only to point out that first order metabolites of the pesticides should be considered in future research.

Losses of large quantities of water as surface runoff from fairways are not uncommon, and in some areas of the U.S., as much as 70% of the incoming water from an average rain event can be lost from the surface of a soil with a moisture content near the saturated condition (*14, 15, 16, 17*). Our simulated fairways were developed on a kaolinite-clay loam soil with a 5% slope. As much as 40% of the rainfall left the surface of the plots if the rain event occurred when the soil moisture content was near field capacity. Also, the simulated rainfall intensity of 3.3 cm hr^{-1}, used in our research, is not uncommon for summer rain events in the Piedmont Region of Georgia.

Analytes with the highest water solubility were found in highest concentration in water collected during the first rainfall event at 24 hr after treatment. The concentrations of nitrate-N, mecoprop, 2,4-D and dicamba, in the runoff water from this rain event, were 12,000, 810, 800, and 360 *u*g L^{-1}, respectively. The less water soluble analytes (benefin, pendimethalin, dithiopyr, chlorothalonil, and chlorpyrifos) were transported at lower concentrations.

The relationship of the analyte fraction transported to the log of the analyte water solubility (pSw) was better fit by a quadratic (R^2=0.96) than a linear function (R^2=0.86) (Figure 1). Higher fractions of water soluble analytes were transported from the treated plots over the duration of the treatment period.

The concentrations of nitrate-N in the runoff water collected 24 hours after treatment (HAT) were slightly above the recommended (USEPA guidelines) maximum contaminant levels (MCL) in potable water of 10,000 *u*g L^{-1}. The concentration of 2, 4-D, in the runoff water was above the recommended MCL of 70 *u*g L^{-1}. Although the treatment conditions were not worst-case-scenarios, there were some conditions that were near optimum for maximum runoff. The soil moisture in the treatment plots was near field capacity at the time of treatment, with a 2.5 cm rain simulation applied to the area 24 hr prior to the treatment. Rainfall in the southern Piedmont Region approximates 2.5 cm per week. At 24, 48, 96 and 192 HAT, the plots received simulated rainfall events at averages of 5.0, 5.0, 2.5, and 2.5 cm, respectively. Therefore, the total weekly simulated rain events were above the average weekly rainfall. Only samples collected over the first 192 HAT contained concentrations of the analytes capable of being detected. The average fractions of water leaving the plots as runoff following the respective simulated rain events were 44.8, 72.1, 40.0, and 35.5% of applied (3). The highest concentrations of the pesticides in the runoff water occurred during the first simulated rain event applied at 24 HAT, and approximately 84% of the recovered analytes were transported during the first two simulated rain events.

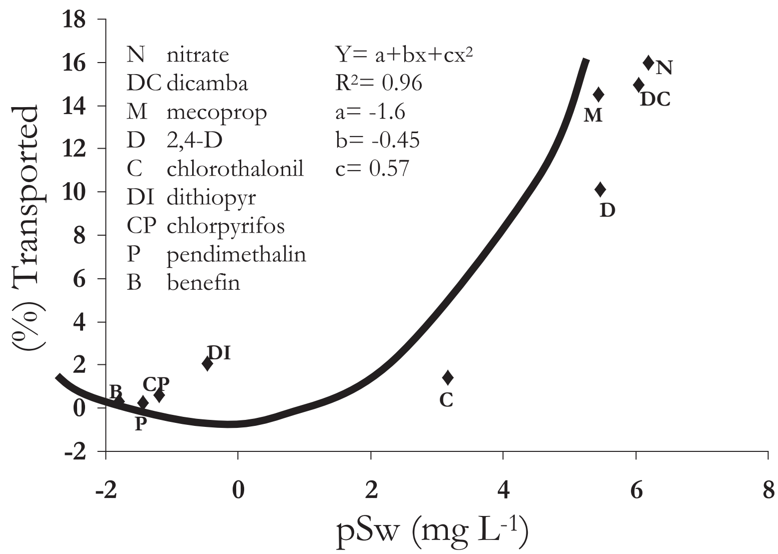

Figure 1. Fraction of the applied pesticides transported from simulated fairways as a function of the log of the analyte water solubility (pSw).

Risk Assessment, Risk Management, and Risk Reduction were phrases commonly used during the presentation of this research. Even though the nature of the risk was not identified, it was apparent that the movement of pesticides into the environment could be managed. We invoked management practices to determine if we could reduce the fraction of water soluble analytes transported from the treated sites. Unpublished research data indicated that the pesticide formulation (salt vs. ester) did not reduce the concentration or the fraction of analyte transported from the treated site at 24 HAT. A buffer area, between the terminus end of the treatment and the collection site, did not affect the fraction of analytes transported, and the concentration was only affected by the dilution factor (ie, less plot area was treated with pesticide). Soil moisture content of 10.9% (near wilting point) at the time of the first simulated rain event (24 HAT) reduced the analyte and the quantity of runoff water by 66% compared to a soil moisture of 18.5% (near field capacity) (unpublished data). Additionally, it was determined that applications of pesticides at the 10.9% soil moisture content followed by a light (1.5 cm) irrigation at 4 HAT reduced the concentration of 2,4-D in the runoff water, at the 24 HAT rain event, to 73 *u*g L^{-1}. This is a ten fold decrease compared to the treatment without the intermediate light irrigation. This would indicate that golf course superintendents could reduce the risk by applying irrigation water at periods following treatment, without reducing pesticide efficacy. Pressure injection of the pesticide at 21.3 MPa reduced the fraction of the insecticide, trichlorfon, transported over the 192 hr treatment period by 80% and the concentration in the 24 HAT collection by 95%, compared to data from the application at 166 kPa (unpublished data). Pressure injection did not increase the transport of trichlorfon through the greens media. A simple change in application technology could result in risk reduction.

Perspective of a Scientist

The age-old question seems to be "Are Golf Courses Friend or Foe of the Environment?" As a scientist, I maintain that grass has such a positive effect on the environment, compared with other crops, and that a manager would have to insult the environment with harmful management practices to negate the positive.

The Bible specifies that grass was ordained by the Creator to be the first life on Earth. "And he said let the earth bring forth grass and the earth brought forth grass…and the evening and the morning were the third day (Genesis 1:11-13)." A blade of grass is the alpha (the beginning) of the visible organic molecules. Grass takes carbon dioxide and water and manufactures complex organic molecules. If the molecules are not in its own domain, it furnishes the intermediates for the grazing animal to finish the manufacturing process. Approximately 50% of the 0.9 billion hectares of land area in the United States are covered with grass; 12 million of those hectares are managed as turf, and 0.8 million are managed as golf courses. It must be pointed out that grass preceded the golfer by several million years as he was brought forth on the sixth day. Walt Whitman wrote "I believe that a blade of grass is no less than the journey-work of the stars." The benefits of grass to the ecosystem have been summarized by Smith (1).

As good stewards of the environment, it is realized that we should continue to lessen the impact of crop management practices, even though the effects of these practices may seem miniscule. Our data indicate that some of the pesticides applied to golf courses have the potential to move into potable water systems. These data were generated from samples taken at the terminus end of the simulated fairway plots and directly under the greens media. It must also be realized that there are many fold (tens of thousands) dilutions occurring to runoff water as it moves toward potable water systems.

The critical issue facing research and regulatory institutions responsible for turfgrass management is the development and interpretation of data on the environmental fate and safety of pesticides used in the management of turfgrass on recreational facilities and home lawns. Safety cannot be measured, but risk can be estimated. Things are deemed safe if their attendant risks are judged to be acceptable. The rapid growth of the turfgrass industry during the last decade placed an urgency on the need for risk assessment of turfgrass management strategies. Risk assessment has always been with us. When cave men recognized that animals could be a source of food, they had to weigh the hazards of being mauled against starvation. There are writings about risk assessment that date back 3,000 years, yet the present concern began in 1960.

Risk management for pesticides begins by decreasing the potential dose through reducing the quantity of a compound in potable water systems. It would be desirable for there to be zero-levels of xenobiotics in potable water systems. Success in the technological development of efficient methods and ultra-sensitive instruments for detecting pesticides has resulted in the identification of some pesticides in water that would not have been detected (zero-level) several years ago.

Therefore, much of the concern for pesticides in drinking water has evolved from quantification of compounds which, because of their constituents, can now be detected at subpart per billion levels. Once the part per million was a visible limit; now we commonly measure analytes in parts per trillion. We will achieve common recognition of a part per quadrillion in the next decade. The 'zero-level' is continually pushed down and we need to recognize what is reasonable for zero-level.

Human risks from xenobiotics is generally defined as Dose x Toxicity. Presently, scientists routinely measure concentrations of pesticides in water to levels of parts per trillion. The USEPA has been working to establish drinking water standards of reference doses for chemicals in surface and ground water, based on the same toxicological research used to establish reference doses (formerly called Acceptable Daily Intake) for food. Until these or similar standards are established by USEPA, it will not be possible to assess the human water-ingestion risk from pesticides that enter the environment.

In hind sight, the following questions should be asked of research programs, such as ours, that quantified potential doses of pesticides where the toxicity is a unitless entity:

*Who really cared?
*Were our data, written in the numerous publications, utilized?
*Was there a demand for more data of this type?
*Was there a clientele for this data?
*Was there a demand for environmental fate data of another type (watershed scale)?
*Was the apparent reduction in funding for pesticide-fate research a reality?

Perspective of an Administrator

Upon entering administration as head of the Department of Crop and Soil Sciences at UGA in 1997, I found that these questions had to be answered for all research programs. The next seven years of my tenure at UGA were laced with decisions on program development, to include filling new and vacated positions for the benefit of the department. This was during a time of reduced federal and state budgets compared to the late 1980's and early 1990's, which directly impacted the formula funding available for program maintenance and development. There was strong competition for positions, and these positions had to be justified by importance to the clientele and potential for generating external funding. The previous questions had to be answered when considering continued funding for the pesticide chemistry program at the Griffin Campus UGA.

The decision for filling either a position in Crop Biotechnology which would be funded by a $1.5M Eminent Scholar Endowment, or a Pesticide Chemistry position with $150K start up funding was not rocket science. At the time there was no way to hire a faculty member in pesticide chemistry with assurance of adequate funding necessary to maintain the high-maintenance laboratory and the necessary technical assistance. During the early 1990's, much of our funding was obtained from the United States Golf Association (Greens Section), Golf Course Superintendents Associations, and formula funding. These funding opportunities decreased greatly at the turn of the century. Historically, the chemical industry has not funded Risk Assessment research to the level that they continue to fund pesticide efficacy research. We received very little funding from the industry for our Pesticide Fate Research Program. Equally important to the decision making was the consideration of the need for the research data. There was no apparent clientele or demand for the data.

Perspective of an Emeritus

Risk Assessment for turfgrass management systems needs to be supported by a consortium of scientists from USEPA, the turfgrass industry, and research institutions. USEPA decides the importance of data and models by defining and enforcing "acceptable-potential risk" based upon the presence of pesticides in the environment, and toxicity to ecosystem components. They will have to incorporate "acceptable levels of environmental risk" into the guidelines for registration and re-registration of pesticides.

The turfgrass industries, including chemical companies, will have to provide the pool of funding for academic research programs. Scientists from research institutions and the chemical industry will provide the unbiased research data important to decisions on risk management. In the past, funding was provided to a number of research programs without coordination of the data type to be accumulated. Field research was performed on plots of various sizes. Laboratory analyses were not unified and data quality was not monitored nor regulated by a uniform Good Laboratory Practices program for comparison of data. This must be rectified to minimize the cost of research while increasing the quality of research. It may be necessary to analyze all water samples at one location to minimize the costs for maintaining several expensive-analytical laboratories. Scientists will have to forgo the pride of maintaining individual programs.

Swan Song

As I overlook the 17th and 18th fairways and greens on the Oconee golf course at Reynolds Plantation and absorb the beauty of the water, forest, and grass environments, I am filled with pride to have been a small part of the research efforts devoted to decreasing the impacts of management practices on these beautiful components of the ecosystem.

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