ASSESSING CHEMICAL HAZARDS ON GOLF COURSES

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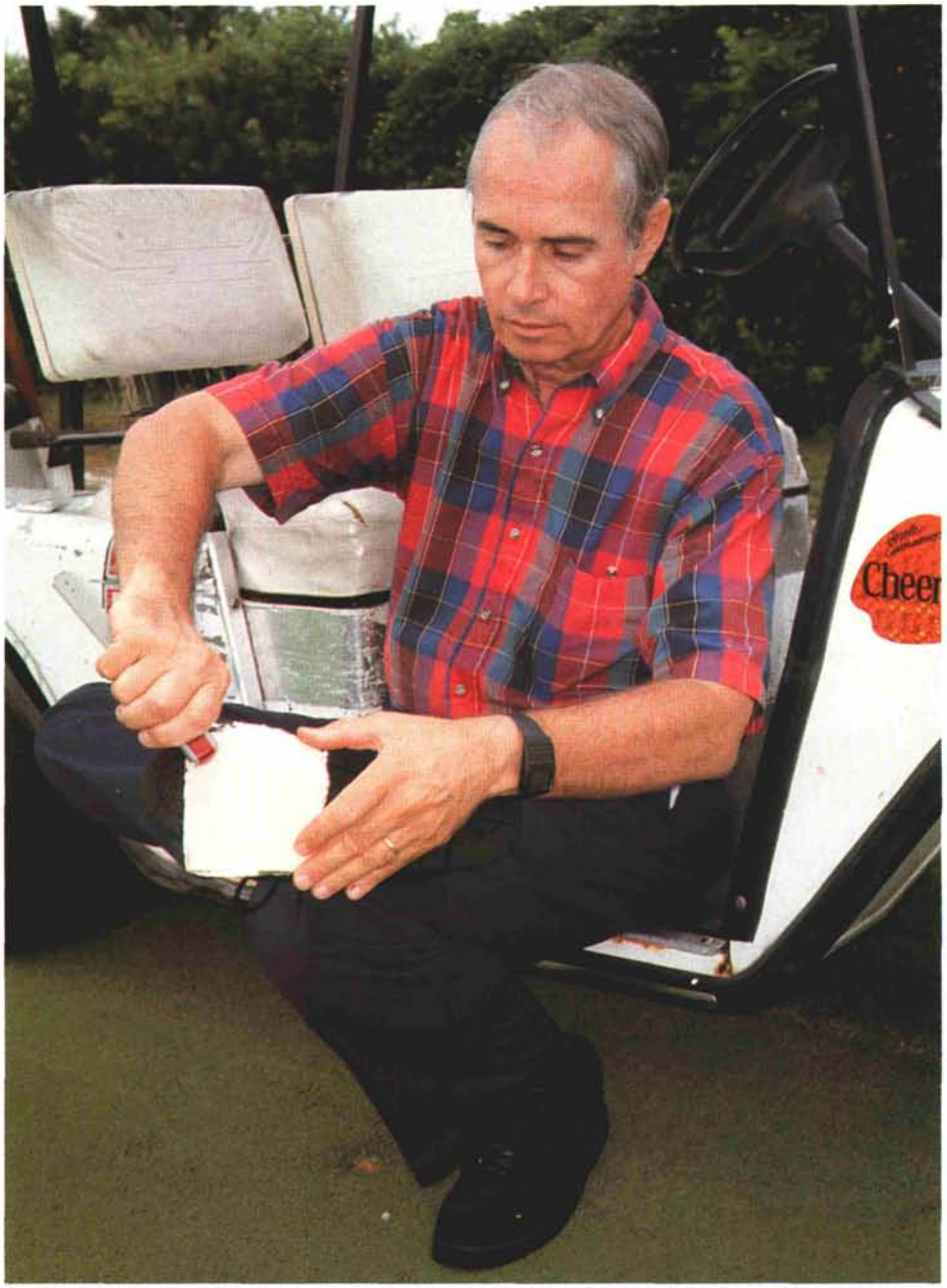
FEAR of chemicals in the environment ranks high on the list of anxieties for many Americans. Because this concern extends to nearly every industry and activity in our society today, it should come as no surprise that fears have arisen in regard to chemicals used on golf courses, such as pesticides.

Before we can decide how concerned we should be about chemicals in our environment, and on golf courses in particular, there are some basic, common-sense rules that should be kept in mind. First, any chemical can produce toxicity in living organisms. Second, for a toxic effect to be produced, an organism must actually be exposed to the chemical and the exposure must result in a dose sufficient to produce toxicity. In other words, the *dose* makes the poison. Third, chemicals have specific and consistent effects.

These simple facts are often misunderstood in our society. Many assume, incorrectly, that the mere presence of a chemical constitutes a health threat. Yet we all know this is not true. If the mere presence of a chemical in our environment could produce health effects, then aspirin could relieve headaches without being swallowed. If the dose did not determine the poison, one glass of wine would be as inebriating as an entire bottle, and it would make no difference if the wine was swallowed or poured on one's feet! If chemicals did not have specific and predictable effects, their use as medicines would be impossible. Too often we fail to apply the common sense of dose and response to chemicals with which we are unfamiliar.

Risk assessment is the application of these and other principles of toxicology to help us rationally decide our level of concern about chemicals encountered in the environment. Risk assessments are methods for comparing levels of chemicals in the environment with doses that produced no ad-



Leather patches, backed with aluminum foil, were stapled to a shoe sole prior to walking on a pesticide-treated turf surface.

verse effects in laboratory animal studies or environmental toxicity tests. These methodologies can be applied to turfgrass systems to help ensure that chemicals are used in amounts and frequencies that do not pose unacceptable health or environmental hazards.

An example of the methodology used to assess the concern about chemicals used on golf courses is illustrated here by considering three pesticides applied to a putting green. Our approach is consistent in principle with the Baseline Human Health Risk Assessment used by the U.S. Environmental Protection Agency (U.S.E.P.A.) to evaluate hazardous waste sites and chemical contamination of soil, but is modified and refined specifically for a putting green. Our assessment is preliminary in nature and should in no way be considered thorough or complete. It is intended only to illustrate some principles of health risk assessment as applied to golf courses and is not a definitive evaluation. Our goal was to suggest how risk assessment methods can be used to address concerns regarding chemicals used on golf courses. We utilized preliminary data to conduct a limited health risk assessment for a putting green and illustrated how such information can assist decision-making regarding levels of chemicals that may warrant concern.

The first step in health risk assessment is to evaluate the ways a person might come into contact with chemicals at a particular site, in this instance a putting green, and to take measurements of chemicals at those points of potential exposure. We evaluated the potential exposure to three pesticides on a putting green for a golfer who plays 18 holes of golf. We considered four pathways of exposure for this golfer. We assumed that this theoretical golfer would 1) kneel on the green to align putts, 2) handle golf club grips that have been laid on the green, and 3) contact the soles of golf shoes while cleaning them after the round. These are dermal exposure pathways, i.e., those that involve absorption of chemicals through the skin.

Because skin is an effective protective barrier against entry of most chemicals into the body, very little chemical that contacts the skin is actually absorbed in most instances. The dermal permeability factor for a chemical reflects the fraction of chemical applied to skin that might actually be absorbed. Although oral exposure pathways would probably be less significant for most golfers than dermal pathways, as an extreme case we assumed that the golfer would 4) clean his golf ball by licking it. This is an ingestion exposure pathway. We assumed that all of the pesticide ingested is actually absorbed into the body because the intestinal tract generally is not an effective barrier to the absorption of organic chemicals.

For the sake of presenting a reasonable maximum exposure, we took measurements 24 hours following application of diazinon, chlorpyrifos (Dursban 2E), and isazofos (Triumph 4E) at rates of 470, 57, and 229 mg active ingredient per square meter of turf. The measurements were taken from a preliminary study conducted on a Tifgreen bermudagrass surface at the Ft. Lauderdale Research and Education Center, University of Florida, and the pesticide analysis was conducted at the Everglades Research and Education Center, Belle Glade, University of Florida. This research on pesticide dislodgeability was sponsored by the Florida Turfgrass Association and by the USGA Green Section.

We measured the amounts of pesticides retained on a) a 10 cm square piece of cotton attached to one knee while kneeling for 10 seconds to simulate aligning a putt, b) a 10 cm square piece of leather attached to a shoe sole following 10 steps on the treated turf surface, and c) a golf ball putted 36 times over a distance of 4 meters per putt. From the amount of pesticide retained on leather shoe bottoms, we estimated the amount that might be retained on leather golf club grips laid on the putting green. These data are presented in Table 1.

Using the levels of pesticides listed in Table 1 for each exposure point, we calculated the dose of each pesticide that a golfer might receive from each of the exposure pathways and summed the doses from all pathways to arrive at the golfer's total dose. The equations used to calculate dermal and oral doses are listed in Table 2. The golfer's

Table 1
Exposure Point Quantities of Pesticides

Quantity of Pesticide on Pant Knee (QP_k)	
Diazinon	0.00994 mg
Isazofos	0.00198 mg
Chlorpyrifos*	0.000025 mg*
Quantity of Pesticide on Shoe Sole (QP_s)	
Diazinon	0.000650 mg
Isazofos	0.000368 mg
Chlorpyrifos	0.000330 mg
Quantity of Pesticide on Grip (QP_g)	
Diazinon	0.0000975 mg
Isazofos	0.0000552 mg
Chlorpyrifos	0.0000495 mg
Quantity of Pesticide on Golf Ball (QP_b)	
Diazinon	0.000775 mg
Isazofos	0.000241 mg
Chlorpyrifos	0.000240 mg

*Chlorpyrifos was not detected on cloth. However, because chlorpyrifos was known to be present on the turf, we used a value of one-half the detection limit of the assay for chlorpyrifos on cloth, which was 0.000025 mg. This approach is consistent with USEPA guidance for "non-detects."

Legend for Table 1

(QP_k): Quantity of pesticide adsorbed to 10 cm square of cotton cloth after kneeling. We assumed two kneeling contacts with turf per hole.

(QP_s): Quantity of pesticide retained on leather soles of size 10 shoes after 10 steps on turf surface. This exposure assumed that the golfer's hands contacted the entire sole of each shoe during cleaning after each round.

(QP_g): Quantity of pesticide retained on two leather club grips was estimated by assuming retention rates equal to the leather shoe sole, and that 15 square centimeters of each club grip contacts the turf.

(QP_b): Quantity of pesticide retained on ball following 36 putts of 4 meters each. We assumed that the golfer licked and swallowed all of the pesticide on the surface of the ball.

total doses were then compared with doses considered by the USEPA to be safe for a person to receive every day for a lifetime (a dosage called the "Chronic Reference Dose," or RfD). Chronic Reference Doses take into account that toxicity can accumulate for some chemicals in some organ systems when the chemical is received as frequently as every day. Although we calculated single doses from one round of golf, we compared these doses with chronic RfDs, which are safe doses that can be received daily for a lifetime. The comparison was made by calculating a "Hazard Quotient," which is the person's total dose divided by the RfD (see Table 3). Doses below the RfD yield Hazard Quotients less than 1, and those greater than the RfD yield Hazard Quotients greater than 1. If the calculated dose is equal to the "safe" dose (RfD), then the Hazard Quotient equals 1.

In order to consider the entire putting green as a unit, we summed the Hazard Quotients for all three pesticides to arrive at a "Hazard Index" for the putting green (see Table 3). This takes into account any potential for additive toxicity from two or more chemicals. A Hazard Index less than 1 would indicate that the person's dose of each pesticide is below its respective "safe dose" or RfD, and that the additive potential does not exceed a "total safe dose." The USEPA considers a Hazard Index less than 1 to indicate that there is no increased health risk. In other words, a Hazard Index less than 1 indicates that all contaminants are present at concentrations below those that could cause effects in humans, even if the chemicals have additive effects.

Table 2
Dermal and oral doses of three pesticides expected from exposure to putting greens during a round of golf

Pesticide	Dermal Dose[1]	Oral Dose[2]	Total Dose
Diazinon	0.0000172 mg/kg	0.0000125 mg/kg	0.0000298 mg/kg
Isazofos	0.0000010 mg/kg	0.0000039 mg/kg	0.0000049 mg/kg
Chlorpyrifos	0.0000002 mg/kg	0.0000039 mg/kg	0.0000041 mg/kg

mg/kg = milligrams pesticide per kilogram body weight

$$[1]\text{Dermal Dose} = \frac{(QP_k + QP_s + QP_g) \times DP}{BW\ (kg)} \qquad [2]\text{Oral Dose} = \frac{QP_b\ (mg) \times ABS}{BW\ (kg)}$$

where:

BW = Body Weight: 62 kg (age-adjusted male body weight)

ABS = Oral Absorption Constant: 100% (assumption for organic chemicals)

DP = Dermal Permeability: DP Diazinon = 0.10
DP Isazofos = 0.025
DP Chlorpyrifos = 0.025

Table 3
Calculation of Hazard Quotients and "Hazard Index" — a comparison of the estimated dose with the Reference Dose (RfD), a dose considered safe for lifetime exposure by USEPA

Pesticide	Total Dose (oral + dermal)	USEPA[a] and OPP[b] RfDs	Hazard Quotients[1]
Diazinon	0.0000298 mg/kg	0.0009 mg/kg/d	0.0331
Isazofos	0.0000049 mg/kg	0.00002 mg/kg/d	0.2450
Chlorpyrifos	0.0000041 mg/kg	0.003 mg/kg/d	0.00137

Hazard Index[2] = 0.2795

[a] United States Environmental Protection Agency
[b] Office of Pesticide Programs
mg/kg = milligrams chemical per kilogram body weight
mg/kg/d = milligrams chemical per kilogram body weight per day

$$[1]\text{Hazard Quotient for Pesticide} = \frac{\text{Total Dose of Pesticide}}{\text{Reference Dose of Pesticide}}$$

[2] Hazard Index for Putting Green = Sum of Hazard Quotients for Pesticides

Preliminary Conclusion

Under the assumptions of this risk assessment, the exposures evaluated could be tripled without exceeding levels considered safe for daily lifetime exposure. Because we compared the doses our theoretical golfer might receive from one round of golf with chronic RfDs, this golfer could receive these doses every day of his life without concern for cumulative toxicity. We caution that this "conclusion" is made as an example only and cannot be applied generally because conditions and pesticide use can vary widely from site to site.

Interpretation of Results and Uncertainty Analysis

The focused risk assessment presented here would indicate that under these theoretical conditions and assumptions, a golfer's exposures to chlorpyrifos, diazinon, and isazofos on putting greens would be considered acceptable because the Hazard Index is much less than 1. But how would we interpret a Hazard Index greater than 1? Although a Hazard Index of 1 or less is considered safe, it is *not* accurate to say that a Hazard Index greater than 1 is therefore unsafe. Because of the large safety factors often employed in developing Reference Doses (10 to 10,000), doses many times greater than the Reference Dose could potentially be all right without adverse effects. A Hazard Index greater than 1 indicates that we are less certain of the potential for adverse health effects from contact with the site, but it does not necessarily indicate that the site is a threat to health. Hazard Quotients and Hazard Indices are interpreted similarly, as summarized in Table 4.

There are numerous sources of uncertainty inherent in the risk assessment process. The extrapolation of toxicity data from laboratory animal studies to human exposure scenarios is an inexact science that introduces much uncertainty into the process. Yet, it is upon these extrapolations that we must often rely to determine doses that are safe from toxicity, such as Reference Doses. Similarly, studies

Table 4
Interpretation of Hazard Quotient and Hazard Index

Dose	Hazard Quotient	Interpretation
Dose < RfD	Dose / RfD < 1	Dose is safe
Dose = RfD	Dose / RfD = 1	Dose is safe
Dose > RfD	Dose / RfD > 1	Safety is less certain

Hazard Index (Sum of Hazard Quotients)	Interpretation
Hazard Index < 1	Site is safe
Hazard Index = 1	Site is safe
Hazard Index > 1	Safety is less certain

Cotton patches, backed with aluminum foil, were pinned over one knee for tests simulating kneeling while aligning a putt.

of chemical absorption are rarely done on human subjects and may be the source of considerable uncertainty in estimating chemical intakes. The dermal permeabilities we used are rough estimates based upon published studies, but a more thorough examination of the literature may yield information that enables us to refine these estimates.

The assumptions we made regarding exposure events and durations are worst-case scenarios and would apply to very few people. Age-adjusted body weights are averages and actually fit only a small number of people. Summing the toxicity scores (Hazard Quotients) of various chemicals may overestimate potential health risks from chemicals that target different tissues and organs. Conversely, the potential for synergistic toxicity is not directly considered in the risk assessment process.

The current means of addressing these uncertainties are through extreme conservatism in all extrapolations and assumptions and by the use of large "uncertainty factors" that reduce the chemical dose considered safe. For example, determination of Reference Doses is typically done by finding the dose at which no effects are produced in rats or mice and dividing that dose by a "safety factor" of 10 to 10,000. These safety factors are used to account for uncertainty and to be sure that even the most sensitive humans would not be adversely affected at the Reference Dose. Use of such large safety factors may often result in RfDs (safe daily doses) that are actually far below a dose that could produce effects in humans. This approach is prudent because the process of health risk assessment is intended to support decision making that is protective of public health and the environment rather than to accurately reflect the toxic potential of chemicals.

Risk assessments are only as applicable and reliable as the data upon which they are based. Without adequate data, our ability to identify true health and environmental hazards is reduced and anxiety over chemicals increases. In the absence of data that is specific and complete, risk assessors must resort to conservative assumptions to ensure that risk assessments overestimate rather than underestimate chemical exposures and toxicities. Costly errors can result when evaluations are made on the basis of inappropriate or poorly documented data. The more accurate the data we use to conduct risk assessments, the more confident we can be that our efforts to protect the public and the environment are appropriate and effective.

The risk assessment we report here, though limited in scope and preliminary in nature, illustrates how the methodology can be applied to turfgrass on golf courses. In order to expand and complete this risk assessment, it is necessary to broaden its scope and to reduce uncertainties inherent in its assumptions. To do this, we must verify and expand the database on pesticide fate, transport, dislodgeability and toxicology, and on human behaviors that result in potential exposure. These data are optimized for risk assessments on golf courses when turfgrass scientists and toxicologists collaboratively design the gathering, testing, and analysis of the data. This risk assessment represents our initial efforts to expand the exposure database and refine the risk assessment methodology for use in golf course management.

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