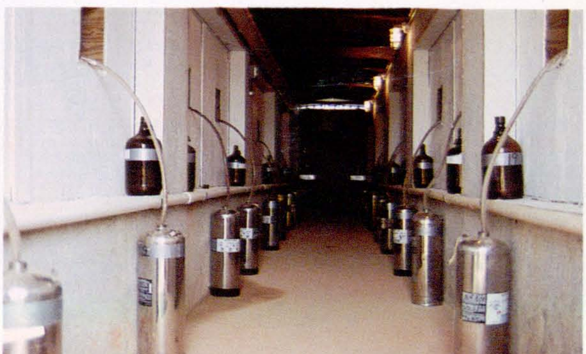
1992 ENVIRONMENTAL RESEARCH SUMMARY



Cover Photos:

During 1992, the second year of a 3-year study on golf courses and the environment, research data from 21 projects was collected. The greenhouse lysimeter facility at the University of Georgia (Griffin) (left) was constructed to simulate golf course greens. Beneath the facility (right), collection canisters allow the researcher to sample the water moving through the soil profile to determine the potential movement of pesticides.

1992
ENVIRONMENTAL RESEARCH SUMMARY

SUBMITTED BY:

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USGA
DAVID B. FAY
Executive Director

May 1993

TO: THE READERS OF THE 1992 ENVIRONMENTAL RESEARCH REPORT

In 1990, the USGA Executive Committee approved a 3-year, $3.2 million study to investigate the effects of golf course activities on the environment. Given the importance of environmental issues in society today, and the environmental scrutiny being directed at golf courses by regulatory agencies and organizations outside the game of golf, there is little the USGA is doing that will have a greater effect on the future of the game.

In the pages that follow you will find the 1992 results of the 21 research projects funded as part of the Environmental Research Program. A primary focus of the study is to determine what happens to pesticides and fertilizers when applied to golf course turf. Ten different projects were funded to investigate this question, and preliminary results are provided in this report.

Not all of the projects funded in the program are 3 years in duration. I am pleased to report that the *Landscape Restoration Handbook*, a 688-page book on how to apply natural landscaping principles to golf courses, has been published and is available now from the USGA. Another important document, which provides a scientific assessment of the environmental benefits of turfgrasses and golf courses, currently is being reviewed for publication in the *Journal of Environmental Quality.*

Looking ahead, results from the 1993 studies will provide many answers and probably raise many more questions. If potential problems are identified, the USGA will endeavor to find solutions acceptable to all.

Sincerely,

Jim Snow

James T. Snow
National Director, Green Section

1992 ENVIRONMENTAL RESEARCH SUMMARY

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Statement of Intent

It is the intent of the United States Golf Association (USGA) Executive Committee, through the USGA Foundation, to collect and disseminate substantial amounts of money for support of research to: 1) improve turfgrasses which substantially reduce water use and maintenance costs; 2) develop management practices for new and established turf which protect the environment while providing quality playing surfaces; and 3) encourage young scientists to become leaders in turfgrass research.

It is anticipated that funds for this purpose will be derived, in major part, from contributions to the USGA Foundation. Additional funds may be derived in the future from royalties attributed to marketable discoveries. The USGA presently intends to return any income received from royalties to the support of turfgrass research. Institutions which accept these research grants will be asked to engage in a free exchange of information with other investigators.

Historically, the sport of golf has maintained a leadership role in the development of improved turfgrasses through the activities of the USGA Green Section. While those developments have helped to provide better playing areas for golf, they have had a far-reaching impact on turfgrass improvement for other uses. Home lawns, parks, school grounds, highway rights-of-way and all other turfgrass uses have been improved by developments which were pioneered by the USGA.

The USGA expects to support research at numerous institutions. In some cases, several will be involved with the development of grasses and maintenance practices where the research may interact and overlap.

In view of this Statement of Intent, it is expected that recipients of grants will embrace a spirit of cooperation and that they will engage in a free exchange of information with other investigators.

Overall Objectives

In 1990, the USGA Executive Committee approved and funded a three year environmental research program. The purpose of this research program is to quantify and document the impact of turfgrass management on the environment. The overall objectives of the project are to:

1. Understand the effect of turfgrass pest management and fertilization on water quality and the environment.

2. Evaluate valid alternative methods of pest control to be used in integrated turf management systems.

3. Determine the human, biological, and environmental factors that golf courses influence.

Understanding and quantifying the degradation and fate of turfgrass pesticides and fertilizers is required for the accurate prediction or simulation of environmental impacts of managed turfgrass systems. Given the current status of research on the environmental impacts of turfgrass, a higher priority was assigned to basic and applied research that would examine the degradation and fate of turfgrass chemicals, rather than research directed toward modeling. After water, pesticide, and nutrient processes have been characterized, development or modification of existing computer models then can proceed.

Alternative methods of pest control have a promising future in the management of turfgrass systems. However, widespread acceptance of these methods by golf course superintendents will require thorough field testing under realistic golf course conditions. Once the scientific documentation of alternative methods of pest control has been completed, they can be incorporated in integrated pest management systems.

Golf courses provide aesthetically appealing greenbelts within our urban and suburban landscapes. However, the human, biological, and environmental factors that golf courses influence need to be scientifically addressed. The future of golf will depend on the implementation of environmentally sound management practices and the development of public information on why "Golf Keeps America Beautiful."

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Environmental Research Budget Summary

Project Subproject	University/Investigator	1991 Actual	1992 Budget	1993 Budget	Total Budget
PESTICIDE and NUTRIENT FATE:					
Leaching	Cornell/Petrovic	104,245	72,000	72,000	248,245
Leaching	MI State Univ./Branham	90,000	130,000	95,000	315,000
Leaching/Volatilization	UC Riverside/Yates	55,000	95,000	150,000	300,000
Leaching/Volatilization	UNL-ISU/Horst-Christians	126,585	133,000	140,488	400,073
Nitrogen Leaching	WA State/Brauen	20,000	25,000	25,000	70,000
Nitrogen Leaching	Univ. NE-Reno/Bowman	20,000	20,000	20,000	60,000
Pesticide Leaching	Univ. FL/Snyder-Cisar	45,000	45,000	45,000	135,000
Pesticide Leaching/Runoff	Univ. GA/Smith	40,000	55,000	55,000	150,000
Runoff	Penn State/Watschke	36,961	53,100	55,722	145,783
Volatilization	Univ. Mass/Cooper	40,000	40,500	40,500	121,000
QA/QC	Independent/Walker	20,000	20,000	20,000	60,000
	SUBTOTALS:	597,791	688,600	718,710	2,005,101
GOLF COURSE BENEFITS:					
Quantification/Validation	Texas A&M/Beard	45,000	0	0	45,000
Wildlife Toxicology	TIWET-Clemson/Kendall	50,000	50,000	50,000	150,000
On Course With Nature	Earth Fund/Harker	25,000	25,000	0	50,000
Human Benefits	Texas A&M/Ulrich	25,000	50,000	0	75,000
	SUBTOTALS:	145,000	125,000	50,000	320,000
ALTERNATIVE PEST MANAGEMENT:					
Biocontrol-Disease	UC Riverside/Casale	13,000	13,000	20,000	46,000
Biocontrol-Disease	Univ. of FL/Elliott	16,000	20,000	20,000	56,000
Biocontrol-Disease	Cornell/Nelson	25,186	27,000	28,000	80,186
Biocontrol-Disease	Iowa State/Hodges	20,000	20,000	25,000	65,000
Biocontrol-Insect	Univ. of Kentucky/Potter	20,000	20,000	20,000	60,000
Biocontrol-Insect	USDA/Klein	20,000	20,000	20,000	60,000
	SUBTOTALS:	114,186	120,000	133,000	367,186
	GRAND TOTALS:	856,977	933,600	901,710	2,692,287

Pesticide and Nutrient Fate

Introduction

Use of chemicals for the control of turfgrass pests, in conjunction with other cultural practices, has had a tremendous effect on the quality of turfgrass grown for golf courses and lawns. Chemical control of pests is only one of the several techniques used on golf courses to sustain turfgrass quality and reduce labor and energy costs.

Despite the obvious cultural and economic benefits, conflicts have developed over pesticide and fertilizer use in relation to environmental quality issues. Chemical residues have been associated with adverse environmental and potential human health effects including: 1) implication of some pesticides as potential human carcinogens, 2) long-term contamination of soils with persistent chemicals, 3) contamination of water resources, and 4) effects on non-target organisms.

Although the existing research results on the fate of chemicals applied to turfgrass is encouraging, much of this available scientific information has been derived from agricultural rather than turf systems or was conducted under a limited set of conditions (i.e., climates, soils, irrigation, turfgrass species, etc.), leaving room for uncertainty.

Based on these concerns, a three-year research program to investigate pressing pesticide and nutrient fate issues specifically relevant to golf course and turfgrass systems was implemented. The overall objective of the research is to understand the mass balance, fate and persistence of pesticides and nutrients applied to turfgrass systems.

These studies cover a wide range of golf course management factors, climates, and sampling methods which include:

- Putting green soil mixtures (sand, sand/peat) and fairway soil textural classes (sand, loam, silt loam)
- Thatch development
- Soil profile sampling depths
- Turfgrass species maintained under golf course conditions
- Irrigation regimes

This section first describes the specific objectives and procedures of each pesticide and nutrient fate research project. Afterwards, the preliminary results for these projects are summarized, in general terms, to note the significance of their findings. The summary includes preliminary results concerning the subsurface and surface loss of nitrogen and phosphorous, and the mobility and persistance of pesticides.

Cornell University

Mass Balance Assessment of Pesticides and Nutrients Applied to Golf Turf - Dr. A. Martin Petrovic

The objective of this project is to more fully understand the fate of pesticides and fertilizers applied to golf turf evaluated over a wide range of conditions. These experiments are being conducted at the ARESTS facility (Automated Rainfall Exclusion System for Turfgrass Studies) which is composed of 3.2 m x 3.2 m (10 ft. x 10 ft.) draining lysimeters (i.e., devices for the collection of water percolating through the soil), a rainout shelter, and an irrigation and drainage collection system. Factors evaluated are three soil textures (acid sand, sandy loam and silt loam) and two simulated growing season precipitation patterns (normal and wetter-than-normal). In this case, rainfall patterns for 1950 and 1917 were used for normal and wet, respectively.

Evaluated, thus far in this study, were applications of mecoprop, triadimefon, and trichlorfon applied to a simulated creeping bentgrass fairway. A ^{15}N labeled urea/methylene urea fertilizer containing phosphorus also was applied and will be monitored during the research project. Measurements taken include clipping yields and leachate from all or some of the lysimeters. The leachate samples are being analyzed for the concentration of nitrate, ammonium, phosphate, mecoprop, triadimefon, and trichlorfon.

Michigan State University

Groundwater Contamination Potential of Pesticides and Fertilizers Used on the Golf Course - Dr. Bruce E. Branham

This project is designed to examine the leaching potential of nitrogen, phosphorus, and pesticides under field conditions. Four lysimeters have been installed at the Hancock Turfgrass Research Center on the Michigan State University Campus. These lysimeters are 1 m^2 (10 ft^2) in surface area and are 1.2 m (4 ft.) deep. The soil within the lysimeters are intact cores that were not disturbed during the construction of the lysimeter. Data from these lysimeters will reflect conditions that occur naturally in the field, and the results will give a clear picture of the leaching potential of the soil (Owosso sandy loam) used in this study.

The project consists of three separate areas. First, the amount of nitrate leaching from late-fall versus early spring applications of ^{15}N labeled urea is being investigated. This study also will examine the fate of nitrogen over a three year period and will focus on the cycling and forms of nitrogen in the soil. Second, five fungicides, two herbicides, and one insecticide will be applied to the lysimeters and leachate will be tested for the presence of these pesticides over the next three years.

The last objective of the study is to examine the mobility of phosphorus in putting green soil mixes. Phosphorus has little mobility in soils with appreciable clay content; however, movement can occur in soils that are mostly sand. This study involves collecting samples from recently constructed greens throughout the United States, and will test these mixes for phosphorus adsorption capacity. Also, phosphorus mobility on pure sand greens will be examined at the Hancock Turfgrass Research Center.

University of California, Riverside

The Fate of Pesticides and Fertilizers in a Turfgrass Environment - Dr. Marylynn V. Yates

The purpose of this project is to study the fate of pesticides and fertilizers applied to turfgrass in an environment which closely resembles golf course conditions in southern California. The goal is to obtain information on management practices that will result in healthy, high quality turfgrass while minimizing the potential for detrimental environmental impacts.

The specific objectives of the project are to: 1) compare the leaching characteristics of pesticides and fertilizers applied to creeping bentgrass greens and bermudagrass fairways; 2) study the effects of soil type and irrigation regime on the leaching of pesticides, nitrates and phosphorus; 3) compare the leaching and volatilization characteristics of nitrates from different fertilizers; 4) measure the volatilization rate of pesticides from turfgrasses into the atmosphere as a function of time after application; and 5) monitor the effects of different irrigation regimes, fertilizers, and soil types on turfgrass quality.

The research site consists of 36 plots, each measuring 3.7 m x 3.7 m (12 ft. x 12 ft.). The fairway area consists of 24 plots, 12 each of two different soil types that have been located randomly in the fairway area. The soil mixture used in the putting green area is a Caltega IV green sand containing 10 percent sphagnum peat. Two different soils are being used in the fairway area to represent the ends of the spectrum in terms of leaching potential, while still being representative of actual golf course soils. One of these is a fine sandy loam, the native soil at the site. The other soil is a fine sand that has been brought to the site.

Irrigation is controlled electronically and scheduling is determined based on the evapotranspiration requirements of the turfgrass. All turfgrass-soil type combinations will be subjected to two irrigation regimes: 100 percent crop evapotranspiration (ET_c) and 130 percent ET_c.

A lysimeter assembly, consisting of five metal cylinders, was placed in the center of each of the 36 plots. Gravel was placed in the bottom of each lysimeter for drainage. The appropriate soil was then added to the lysimeters. To ensure uniform soil conditions, the soil was hand packed to the same bulk density in each of the barrels.

University of Nebraska
Iowa State University

Pesticide and Fertilizer Fate in Turfgrasses Managed Under Golf Course Conditions in the Midwestern Region - Dr. Garald E. Horst and Dr. Nick E. Christians

The objective of this research is to determine the influence of pesticide, fertilizer and irrigation management practices on the persistence and mobility of nitrogen and selected pesticides in turfgrass systems. Soil columns were sampled from the field to monitor pesticide and nitrogen movement. Intact, undisturbed soil columns also are removed from the field and grown in the greenhouse under conditions which simulate the field turf-soil environment. The greenhouse soil columns allow measurement of nitrogen and pesticides in leachate to complete the balance-sheet of their fate in the turfgrass system.

Research sites with established stands of Kentucky bluegrass were selected at the John Seaton Anderson Turfgrass Research Facility near Mead, Nebraska, and at the Iowa State University Horticulture Farm, Ames, Iowa. The experimental areas were treated with recommended rates of urea fertilizer, Trimec® (2,4-D, mecoprop and dicamba) and pendimethalin herbicides, isazofos and chlorpyrifos insecticides, and the fungicide metalaxyl.

Twenty centimeter diameter turf-soil cores were excavated to a depth of 61 cm from local field environments and transported to the laboratory one week prior to application and approximately 1, 14, 30, 60 and 120 days after application. Four cores were removed on each sampling date at each location. The cores were sectioned into verdure, thatch, mat and multiple soil depths, and then prepared for residue analysis.

Experiments addressing the fate of nitrogen and phosphorus were conducted at Iowa State University. Fourteen soil columns were encased in cement, extracted from the field, and transported to the greenhouse. Nitrogen and phosphorus were applied to the columns and two watering regimes of 2.54 cm (1 inch) immediately following nutrient application and four 0.63 cm (0.25 inches) applications during a one-week period were used to determine the effects of irrigation rates on nitrogen volatilization and movement through the turf/soil profile.

Washington State University

Quantification and Fate of Nitrogen from Amended Sand Putting Green Profiles - Dr. Stanton E. Brauen and Dr. Gwen K. Stahnke

The Pacific Northwest has a history of constructing sand greens from pure sand, some with coarse particle sizes and without amendment, to reduce the cost of construction. A major concern is whether nitrate nitrogen leaching from putting green profiles constructed of sand alone, or peat/soil amended sand, can be prevented through efficient irrigation practices, efficient nitrogen fertilizer application, reduction in total nitrogen fertilization rate, or use of deeper sand profiles. This research project will evaluate the susceptibility of these systems to nitrate nitrogen leaching and provide guidance for its correction, reduction or elimination.

Lysimeters were constructed during 1991 from local funds and labor. Thirty-six of the 1.2 m x 2.5 m (4 ft. x 8 ft.) lysimeters were seeded to creeping bentgrass in early October and were overseeded to local ecotypes of annual bluegrass in the spring of 1992. The turf is managed as a putting green and traffic is applied with a Brinkman traffic simulator equipped with golf cleats.

The growing medium consists of 30 cm (12 inches) of USGA specification sand, either alone or amended with ten percent sphagnum peat and two percent fine sandy loam soil. The three annual nitrogen application rates are 195, 390, and 585 kg ha^{-1} yr^{-1} (174, 348, and 526 lbs. per A respectively) and two application methods (granular slow release/soluble N fertilizer in four-week applications and biweekly granular slow release N with liquid ammonium sulfate).

Leachate data collection began the last week of October, 1991, with the beginning of fall rains. Soil-water percolate from each lysimeter is monitored and quantified on 24 hour intervals during leachate production periods. Leachate samples are analyzed by nitrate and ammonium ion sensitive electrodes and ion analyzer.

University of Nevada, Reno

The Effect of Salinity on Nitrate Leaching from Turfgrass - Dr. Daniel C. Bowman, Dr. Dale A. Devitt, and Dr. Wally W. Miller

This project was initiated in March of 1991, and has a field (Las Vegas) and greenhouse (Reno) component to examine the effects of saline irrigation water on nitrate leaching from a soil root zone and on nitrogen uptake by turfgrasses.

Las Vegas: The irrigation system and sampling hardware (lysimeters, tensiometers, neutron probe access tubes, ceramic extraction cups, and associated plumbing) were installed at Horseman's Park in southeast Las Vegas during the spring and summer. Plots were then seeded with either 'NuMex Sahara' bermudagrass or 'Monarch' tall fescue at rates of 50 and 393 kg ha^{-1} (45 and 350 lbs. per A), respectively. Each turf was established under typical fairway management conditions. Bermudagrass plots were overseeded with Palmer/Prelude perennial ryegrass in October. The saline irrigation treatments were initiated in January 1992, after which data collection began.

Reno: Seventy-two 15 cm (6 inches) diameter by 61 cm (24 inches) deep soil columns were equipped with ceramic extraction cups embedded in diatomaceous earth and back filled with a loamy sand. Each extraction cup is connected by tubing to individual collection bottles, which are in turn connected to a common vacuum line. The 36 columns then were seeded with either 'NuMex Sahara' bermudagrass or 'Monarch' tall fescue at the rates discussed above. Establishment and growth was rapid in the greenhouse for both species, and a dense sward has developed. Columns were fertilized once each month with ammonium nitrate at a rate of 50 kg N ha^{-1} (45 lbs. per A). Supplemental iron was added regularly to correct some incipient chlorosis in the young bermudagrass. The leaching fraction treatments were started in January, 1991, and samples were collected weekly and analyzed for nitrate and ammonium.

Pennsylvania State University

Surface Runoff of Pesticides and Nutrients Applied to Golf Turf - Dr. Thomas L. Watschke

Research plots were established with creeping bentgrass and perennial ryegrass on a sloped area to evaluate pesticide and nutrient runoff. Shortly after germination, irrigation was used to produce steady-state runoff, and hydrographs were generated from the runoff data. In 1992, leachate and runoff samples were evaluated for nitrogen and phosphorous levels. Currently, pesticide concentrations in runoff and leachate are being analyzed.

University of Massachusetts

Volatilization and Dislodgeable Residues of Pesticides and Nutrients Applied to Golf Turf - Dr. Richard J. Cooper and Dr. John M. Clark

The objective of this study is to determine the gaseous losses (volatilization) and dislodgeable foliar residues of pesticides applied to golf course turf. To date, limited work has shown that volatile loss of some pesticides applied to turf approaches 15 to 25 percent of the total applied.

Airborne pesticide residues were assessed using the high-volume/theoretical profile shape method (i.e., high volume suction fan sampling air above the turfgrass area). Dislodgeable residue samples are determined by vigorously wiping cheese cloth over several one-square-foot areas. During the last two years, volatile and dislodgeable samples for pesticides were collected over a two week sampling period. Samples were extracted and stored for future analysis.

University of Florida, IFAS

Mobility and Persistence of Turfgrass Pesticides in a USGA Green - Dr. George H. Snyder and Dr. John L. Cisar

The purpose of this project is to evaluate percolate water from a USGA-specification green and evaluate various methodology practices for pesticide analysis.

Stainless-steel lysimeters were installed in a USGA-specification green at the University of Florida, IFAS, Ft. Lauderdale Research and Education Center. They were fitted with stainless-steel lines for off-site collection of percolate water. Lysimeter performance was tested in three ways to determine the completeness of sample recovery and to investigate the effect of sample residency time. It was determined that recovery equaled or exceeded 97 percent.

Methods were validated for determining certain organo-phosphate pesticides in percolate water, thatch, soil, and grass clippings. In 1992, the fate of six pesticides were evaluated and the methods were developed for determining dislodgeable residues.

University of Georgia

Evaluation of the Potential Movement of Pesticides Following Application to a Golf Course - Dr. Albert E. Smith and Dr. David C. Bridges

The objectives of this project are to: 1) determine the potential movement of pesticides from treated bermudagrass and bentgrass greens into surface runoff and groundwater, and 2) determine the potential movement of pesticides from treated bermudagrass fairways into surface runoff and groundwater.

The greenhouse lysimeter facility has been constructed to simulate golf course greens with 'Penncross' bentgrass and 'Tifgreen' bermudagrass turf. Thirty-six individual lysimeters were constructed by mounting a turfgrass growth-box on a PVC column containing a soil profile developed according to USGA specifications. An automatic track-irrigation system was developed for controlling the rates and time for irrigation. The daily irrigation of 0.63 cm (0.25 inches) of water and a weekly rain event of 2.54 cm (1 inch) are controlled by an automatic timer. Pesticide treatments began for this project in October, 1991.

The field lysimeter facility consists of small bermudagrass and bentgrass greens established on 56 cm (22 inches) diameter lysimeters installed below the sod. The 20 lysimeters have drainage lines installed at the bottom of the lysimeter for collection of leachate from the soil profile developed according to USGA specifications.

Table 1. Summary of subsurface and surface nitrogen loss research projects conducted under golf course conditions which have reported data.

University and Researchers	Fertilizer Fate Treatments Evaluated	Pesticides Fate Treatments Evaluated	Irrigation	Soil	Turfgrass Area	Measured Parameters
Pennsylvania State University Dr. Thomas Watschke	Mixed sources include NH_4NO_3 and urea compounds. Three 49 kg N ha^{-1} rates were applied (Fall 1991, Spring and Fall 1992)	Triumph (isazophos), Proxol (trichlorfon), Bayleton (triadimefon), MCPP (mecoprop)	Enough to force runoff plus natural precipitation.	Silt loam	Creeping bentgrass and ryegrass fairways	Leachate and Runoff
Michigan State University Dr. Bruce Branham and Dr. Paul Rieke	Early spring/late fall. Total added is 196 kg ha^{-1} yr as urea.	2,4-D, dicamba, Triumph (isazophos), Daconil (chlorothalonil), Subdue (metalaxyl), Bayleton (triadimefon), Banner (propiconazole), nitrogen (as urea), and phosphorous	Normal irrigation to maintain turf.	Sandy loam	Kentucky bluegrass rough	Leachate
Cornell University Dr. Martin Petrovic	Labeled methylene urea applied in four applications (45 kg ha^{-1}).	Triumph (isazophos), Proxol (trichlorfon), Bayleton (triadimefon), MCPP (mecoprop)	Normal and wet rainfall year with additional irrigation.	Coarse sand, sandy loam, and silt loam	Bentgrass fairways	Leachate
Iowa State University and University of Nebraska Dr. Garald Horst, Dr. Pat Shea, and Dr. Nick Christains	Labeled urea applied to undisturbed soil columns.	Trimec (2,4-D, mecoprop, and dicamba), pendimethalin, Triumph (isazophos), Dursban (chlorpyrifos), Subdue (metalaxyl), Daconil (chlorothalonil), and nitrogen and phosphorous	After fertilization, 2.5 cm as one application and 0.625 as 4 small increments .	Silt loam	Kentucky bluegrass rough	Leachate and Volatilization
University of California Dr. Marylynn Yates	Urea and SCU at 134 and 268 kg ha^{-1} yr	2,4-D, MCPP, Betasan (bensulide), Balan (benefin), Dacthal (DCPA), Sevin (carbaryl) or bendiocarb or Oftanol (isofenphos), Subdue (metalaxyl) or PCNB	Two irrigation regimes, 100% ET_c and 130% ET_o	Sand/peat mix for greens and sandy loam and loamy sand for fairways	Bermudagrass fairways and creeping bentgrass greens	Leachate
Washington State University Dr. Stan Brauen and Dr. Gwen Stahnke	Mixed granular and soluble nitrogen % at 2 application timings (14 and 28) and 3 rates (195, 390, and 585 kg ha^{-1})	To maintain turf only - not part of study objectives	Normal irrigation to maintain turf.	Sand and sand/peat putting green mixes	Creeping bentgrass green	Leachate
University of Nevada Dr. Dan Bowman and Dr. Dale Devitt	NH_4NO_3 applied monthly at 50 kg ha^{-1}	To maintain turf only - not part of study objectives	Various concentrations (15 to 60 ppm) of a saline water source used to irrigate turf.	Loamy sand	Bermudagrass fairway and Tall Fescue rough	Leachate
University of Georgia Dr. Al Smith and Dr. David Bridges	To maintain turf only - not part of study objectives	Weedar 64 (2,4-D amine), Bueno 6 (MSMA), Banvel (dicamba), MCPP (mecoprop), Ronstar (oxidiazon), Betasan (bensulide), Daconil (chlorothalonil), Dursban (chlorpyrifos)	0.625 cm daily and one 2.54 cm weekly event to simulate rainfall.	USGA putting green recommendations comparing 80:20 and 85:15 sand/peat rootzone ratios by weight	Creeping bentgrass and bermudagrass putting greens	Leachate
University of Massachusetts Dr. Richard Cooper and Dr. John Clark	To maintain turf only - not part of study objectives	Triumph (isazophos), Proxol (trichlorfon), Bayleton (triadimefon), MCPP (mecoprop)	Normal irrigation to maintain turf.	Silt loam	Bentgrass fairway	Volatilization and dislodgeable residues
University of Florida Dr. George Snyder and Dr. John Cisar	To maintain turf only - not part of study objectives	Nemacur (fenamiphos), Dyfonate (fonofos), Dursban (chlorpyrifos), Triumph (isazophos), Oftanol (isofenphos), Mocap (ethroprop)	Normal irrigation to maintain putting green turf in south Florida	USGA putting green recommendations.	Bermudagrass putting green	Leaching and dislodgeable residues

1 lb. per acre = 1.12 kg ha^{-1} 1 inch = 2.54 cm 1 ppm = 1 mg L^{-1}

Fate of Nitrogen and Phosphorus

The degree of nitrate leaching from turfgrass systems, as noted in the literature, has been found to be variable. In previous research, dramatic differences in nitrate leaching were reported by different researchers ranging from 0 percent to 80 percent of the total applied nitrogen (Walker and Branham, 1992). Factors that influence the degree of nitrate leaching include soil type, irrigation and rainfall, temperature, nitrogen source and rate, and season of application. Currently, several research projects are focusing on the fate of applied nitrogen and phosphorus compounds under different turf and climatic regimes. The research being conducted on nitrogen movement and transport is addressing many of these factors (Table 1).

Although the experiments have not been completed, some comparisons are possible from the data generated thus far. These include gross comparisons on nitrate leaching observed per annum in all projects, comparisons between nitrate leaching in different climatic zones with different soil types, and comparisons between application method and source of nitrogen. As more data is collected, and the scientists conducting the studies have time to review their results, these preliminary conclusions may be strengthened or refuted.

Subsurface Loss of Nitrogen

Thus far, the three most interesting factors affecting subsurface nitrogen loss are application rate, soil type, and irrigation method. Preliminary results suggest a very strong trend exists between rate of nitrogen application and leaching losses of nitrogen as nitrate (Figure 1). This data is from all

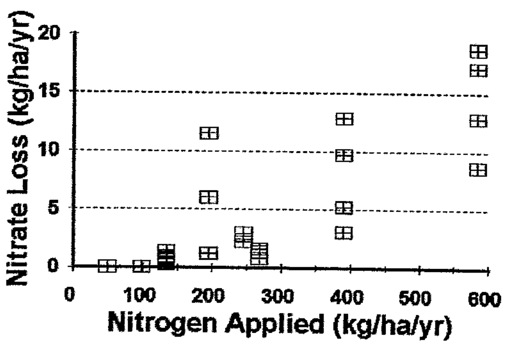

Figure 1. Effect of nitrogen application rate on subsurface nitrogen loss (1 lbs./A = 1.12 kg ha^{-1}).

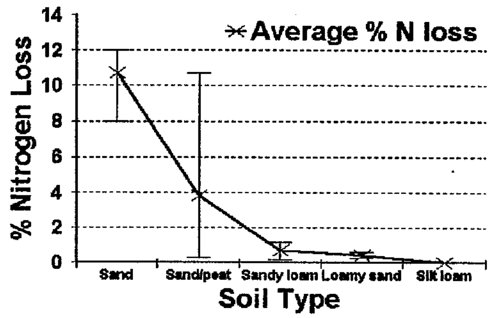

Figure 2. Effect of soil type on subsurface nitrogen loss. Percent nitrogen loss is averaged over studies reporting results for the various soil types. The range of values reported is represented with the 'I' bar.

five research projects reporting data which was summarized earlier (Table 1). As noted here and in other publications, the subsurface loss of nitrogen is most dependent on total rate of application.

The relationship between soil type and subsurface loss of nitrogen agrees closely with previous research conducted on both turf and agricultural systems (Figure 2). For this report, the results were compiled from the five university research projects (Table 1) for all soil types (sand, sand/peat, sandy loam, loamy sand, and silt loam) and all nitrogen application rates (ranges from 134 to 580 kg N ha^{-1} yr^{-1} or 120 to 518 lbs. per A annually). As noted earlier, the greatest percent loss of nitrogen was observed for the sand and sand/peat mixtures compared to the loamy sand, sandy loam, or silt loam soils. However, it is important to note that the addition of the peat to sand significantly reduced the amount of nitrogen loss through subsurface leaching compared to the sand alone. As the rates of nitrogen application decreased from high levels to more moderate levels (less than 300 kg N ha^{-1} yr^{-1} or 268 lbs. per A annually), the results from sand/peat mixtures were virtually indistinguishable from the sandy loam or loamy sand soils.

At Pennsylvania State University (Watschke et al.), 49 and 98 kg N ha^{-1} yr^{-1} (44 and and 88 lbs. per A, respectively) of granular soluble nitrogen were and perennial ryegrass. The higher rate was applied in two (spring and fall) 49 kg ha^{-1} treatments. The plots were irrigated to produce runoff with a total of 37.8 cm (15 inches) of water applied per year (August 1991 to September 1992). In most cases, nitrate found in leachate was equal to or significantly below the amount found in the irrigation water (typically 1 to 6 mg L^{-1}). Mean annual nitrate concentrations from all sampling events was usually less than 1 mg L^{-1}, indicating that less than 0.5 percent of the total applied nitrogen was leached through the turf and silt loam soil.

Research at Michigan State University (Branham et al.) examined nitrate leaching following both early spring and late fall applications of urea at 196 kg N ha^{-1} yr^{-1}. Thus far, an accumulated total of 2.3 kg ha^{-1} of nitrate has been found within the 38 leachate samples collected from the early spring treatment or only 0.9 percent of the total applied (sampling occurred for more than a year; thus, total applied N for the entire study duration is 245 kg ha^{-1}). Average nitrogen concentrations in the samples were only 0.5 mg L^{-1}. The highest observed leachate concentration for the entire sampling period was slightly less than 3 mg L^{-1}. There was no detectable nitrate in any of the leachate samples collected in the most recent sampling (October 1992).

For the late fall treatment, slightly greater nitrogen leaching occurred, or 1.2 percent of the total N applied. The mean concentrations in leachate samples were also slightly higher, or 0.76 mg L^{-1}. For this treatment, both nitrate and ammonium were still detectable in the most recent leachate samples, but it represents a very low level of nitrogen leaching. The fact that little difference was noted between early spring and late fall nitrogen applications suggests that turf systems are much more efficient users of nitrogen compared to agricultural systems. In agricultural systems, late fall application rates tend to increase the potential for spring "flushes" of soluble nitrogen and subsequent off-site transport as leachate or snow-melt runoff.

Researchers at Washington State University (Brauen et al.) have examined the effect of nitrogen application timing and rate on leaching from putting green rootzone mixes of sand and amended sand/peat mixtures. The rates of application were moderate to high (195, 390 and 585 kg N ha^{-1} yr^{-1}). Application frequency varied from 11 times annually to 22 times annually. Highest leaching percentages were noted for nitrogen applied to sand alone (mean = 10.7 percent of the total N applied regardless of application timing) compared to the amended sand/peat mixtures (mean = 6.0 percent of total N leached). In addition, the total nitrogen leached was always highest for the higher rates of nitrogen application, although this did not necessarily correlate when expressed as percent released as a function of the total nitrogen applied.

Total nitrogen leached also was not well correlated to application timing, as little difference was noted in leaching characteristics of the 22 applications per year versus the 11 applications per year treatment. One interesting observation was that despite the relatively high percentages of nitrogen leached, the leachate concentrations never exceeded 10 mg L^{-1}. Data from the 1992-1993 season should provide an interesting comparison since the turf should be better established with a more mature root system.

Researchers at Iowa State University (Starrett et al.) reported that single 2.54 cm (1 inch) or four 0.63 cm (0.25 inch) irrigation applications to silt loam soil columns removed from an established Kentucky bluegrass turf had little effect on the leaching characteristics of applied nitrogen (49 kg N ha^{-1}). In both cases, applied N was found primarily in the thatch layer (about 12 to 16 percent of total applied N) and the first 10 cm (4 inches) of soil below the thatch layer (24 to 26 percent of the total applied). Leachate from the columns was always less than 1 percent (cumulative) of the total applied (Figure 3).

At University of California (Yates et al.), nitrogen movement was examined in field plots after application of urea or sulfur coated urea at rates of 134 or 268 kg ha^{-1} yr^{-1} (120 or 240 lbs. per A annually) to amended sand putting greens or fairway loamy sand and sandy loam soils. As with the other projects, it was noted in all cases that less than one percent of the applied nitrogen leached

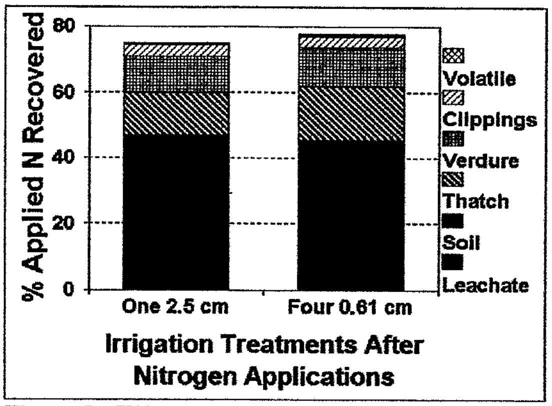

Figure 3. Effect of irrigation method on nitrogen balance after fertilizer application.

during the course of the study. Highest leachate concentrations were noted for either sulfur coated urea or urea applied to sandy loam soils. Two concentrations reported were equal to 128 mg L^{-1}, but occurred for turfgrass establishing in disturbed soil. Most leachate samples ranged from less than detectable to about 6 mg L^{-1}. The few treatments that produced high concentrations were also noted for having the least amount of applied water leach through the profile; hence, the annual concentrations would be expected to be high. Samples with higher concentrations still represented less than 0.5 percent of the total nitrogen applied.

Surface Loss of Nitrogen

Researchers at Pennsylvania State University (Watschke et al. 1992) observed runoff following nitrogen applications on sloped fairway plots established to creeping bentgrass and perennial ryegrass. Prior to nitrogen application, hydrographs for the different plots were observed as the turf matured. They noted that a significantly different hydrograph developed for each species over time. Runoff was found to occur more quickly and with greater peak flow from the ryegrass plots than from the bentgrass plots. By midsummer 1992, it was found that twice the amount of applied water was required to produce runoff on the bentgrass compared to the ryegrass plots.

Regardless of the turf cover used, runoff concentrations of applied nitrogen did not appear to be different for the different species of turfgrass. These results are consistent with those of other researchers: runoff decreases with an increasing amount of soil cover (whether turf or row crop), and turfgrass, due to its dense cover, not only attenuates surface losses of water but reduces the potential for surface and subsurface losses of nitrogen as well.

Subsurface and Surface Loss of Phosphorus

Pennsylvannia State University researchers (Watschke et al. 1992) also have examined phosphorus leaching and runoff from the same plots noted earlier. The two application rates of monoammonium phosphate were either 5 or 10 kg ha^{-1} yr^{-1} (where the higher rate of application was performed in two split applications). Phosphate concentrations in leachate never exceeded the irrigation water content of 1 to 2.5 mg L^{-1} (1 to 2.5 ppm) through the duration of the study. This is not surprising given the high affinity of phosphate for soil particle surfaces, which effectively decrease leaching potential.

Phosphate concentrations in surface runoff were found to be higher than those observed in the irrigation water for 8 of the 11 samples examined after application of the second 5 kg ha^{-1} treatment. The concentrations observed were still less than 6 mg L^{-1} (6 ppm) phosphate, and represented a low percentage of the total applied. Loss of phosphate in both agricultural and turf systems usually occurs through sediment loss and transport during golf course construction or turf establishment. Once turf matures, it is likely that significant losses of phosphorus will only occur during runoff events immediately after fertilizer application.

Fate of Pesticides

A variety of research projects are underway that address several key pesticide fate issues concerning golf courses. These include studies that determine the persistence and mobility of pesticides commonly used in golf course construction and maintenance, the principal turfgrass components where applied pesticides tend to reside, the effect of different turfgrass components (i.e., thatch, soil, clippings) on the fate of applied pesticides, the dislodgability of applied pesticides, and the volatility patterns of applied pesticides. Current understanding of how turfgrass systems respond to and alter pesticide persistence and mobility has considerable gaps compared to agricultural systems. The research results reported here and in future reports will provide the basis for sound and scientific assessment of pesticide fate and transport in turfgrass systems.

Mobility and Persistence of Pesticides

Thus far, four research projects have provided preliminary data relating to the fate of applied pesticides in turfgrass systems. At the University of Florida (Snyder et. al.), results on the mobility and persistence of five different organophosphate pesticides applied to a bermudagrass green were reported. The compounds include fenamiphos, fonophos, chlorpyriphos, isazophos, and isofenphos (Figure 4). In the first study, both fenamiphos and fonophos were applied at rates of 11.25 and 8.8 g m^{-2}, respectively, followed by a second application at the same rates approximately 90 days later. Following application, the plots were irrigated and

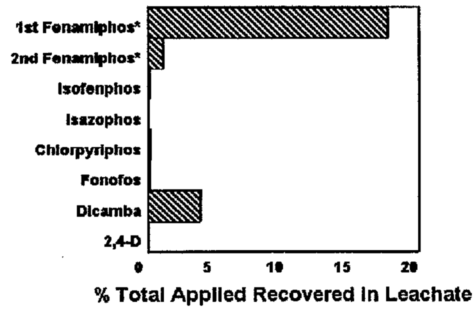

Figure 4. Recovery of Several Pesticides Averaged over Project Locations. More of the fenamiphos (*) metabolite (breakdown product) was found in the first application than the second one applied 90 days later.

samples of leachate, soil, thatch, and clippings were collected on a regular basis (1, 3, 5, 7 days after first application and 3, 7 and 10 days after the second application).

Fonophos was found to have a high affinity for the thatch layer compared to soil. Its concentration decreased rapidly during the first five days and then more slowly through the duration of the measurements. Leachate concentrations were very low (less than 3 to 10 percent of total applied).

Fenamiphos was found to degrade quickly in the thatch as well, but two metabolites (or breakdown products) of the compound appeared within a day of the first application. The metabolites decreased over time, but were found in higher concentrations than the parent compound. The fenamiphos metabolites also were found primarily in the soil, suggesting a higher water solubility. The second application was found to have much less percolate metabolite, decreasing from 17.7 percent of the total applied in the first application to 1.1 percent of the total in the second application.

Similar experiments were conducted at the University of Florida for chlorpyriphos, isazophos, and isophenphos. Chlorpyriphos was found to partition in the thatch portion of the putting green. None of the compounds were found in significant amounts with in leachate samples. The chlorpyriphos which leached through the putting green was only 1.7 percent of the total applied for the first application, but was less then 0.5 percent after the second application. The reported izasophos and isofenphos losses were even lower.

Researchers at the University of Nebraska and Iowa State University (Horst et al. 1992) examined the mobility and persistence of four pesticides in established stands of Kentucky bluegrass. To date, they have found the following leaching characteristics based on 60 cm (24 inches) depth cores: metalaxyl > isazophos > chlorpyriphos = pendimethalin (Figure 5). They also noted that metalyxyl and pendimethelin were the most persistent compounds. An important finding from this project is the apparent increase in degradation rate for these compounds in the turfgrass system compared to degradation rates for the same compounds in agricultural systems.

University of Georgia researchers (Smith et. al.) evaluted the leaching characteristics of both soluble and insoluble formulations of 2,4-D and dicamba applied to greenhouse and field lysimeters with 85:15 and 80:20 sand/peat putting green root zone mixes. The results indicate that no significant difference was noted for leaching of the soluble and insoluble 2,4-D compounds under either field or greenhouse lysimeters. Less than 1.2 precent of both 2,4-D compounds was leached through the lysimeters. Application of the 2,4-D ester (less water soluble form) was not detected in the leachate, while the acid form was, suggesting that the ester was hydrolized and then transported. Less than 4 percent of the total dicamba applied was transported to leachate in the greenhouse lysimeters and even less in the field lysimeters.

The investigators also compared these results to model predictions based on the GLEAMS agricultural model. It was found that significant quantities (almost 0.04 mg L^{-1} or 45 ppb) of 2-4,D were predicted to appear in the leachate. However, the

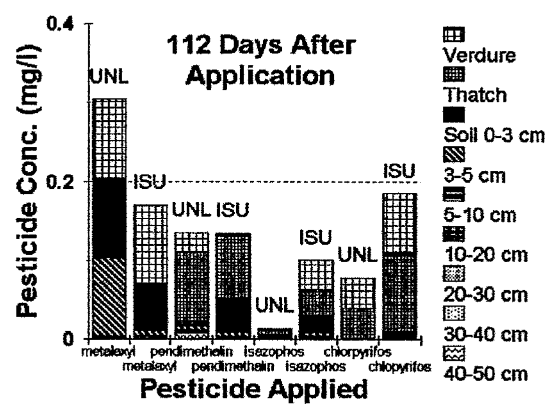

Figure 5. Concentration (mg L^{-1}) of several pesticides throughout turf and soil profile 112 days after application.

actual concentrations never exceeded 0.005 mg L^{-1} or 5 ppb (Figure 6). This is important since it suggests that turf systems are much more efficient at reducing soluble pesticide leaching compared to agricultural systems. As noted in the nutrient section, the application of nitrogen or pesticides to unamended, coarse sandy soils should be avoided. Modification of these sands with peat or other organic material will serve as a very effective means of reducing subsurface loss of pesticides and nutrients.

At Cornell University (Petrovic et al.), researchers examined the leaching characteristics of triadimefon and MCPP under two different precipitation scenarios and three different soils. Precipitation had little effect on the transport of triadimefon under either moderate or high irrigation. More triadimefon (1 to 2.44 percent of the total applied) was leached from sand alone than either the sandy loam (0.01 to 0.06 percent of total applied) or the silt loam soil (0.24 to 0.28 percent of total applied). On the other hand, MCPP leaching was strongly dependent on irrigation treatments applied to the sandy soil. Application of MCPP to slightly heavier textured soils (i.e., sandy loam and silt loam) reduced the amount transported to less than 1.7 percent of the total applied for all cases.

Volatility and Dislodgeability

Studies conducted at the University of Massachusetts (Cooper et al.) and University of Florida (Snyder et al.) have addressed different aspects of pesticide volatility (i.e., gaseous loss into the air) and dislodgeability (i.e., amount of pesticide which comes off the turf when in contact with skin or clothing). Researchers at the University of Masschusetts have investigated both volatility and dislodgeable foliar residues of pesticides (triadimefon, trichlorfon, MCPP and isazophos) after application to a bentgrass golf course fairway. Volatile loss was measured as source flux after application or mg m^{-2} d^{-1}. Trichlorfon and isazophos showed volatile losses of 4.9 and 4.6 percent of the total applied during the first day of application. Trichlorfon volatility was still significant three days after application with about 3.3 percent of the applied pesticide measured as a volatile loss. Isazophos, on the other hand, quickly decreased to less than 1 percent of the total applied in only the second day after application. Triadimefon samples were lower, with about 3 percent of the total applied being measured as volatile loss after the first day and decreasing to less than 1 percent of the total applied after the second day. MCPP applications produced the lowest results, with less than 1 percent of the total applied measured as a volatile loss.

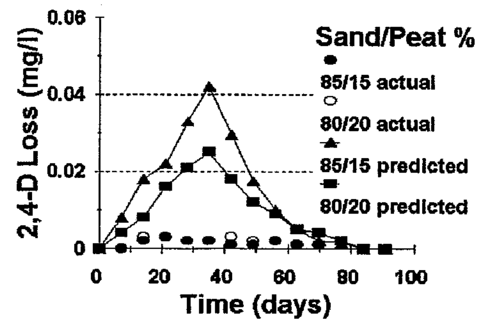

Figure 6. Comparison of predicted (GLEAMS model) and actual 2,4-D leached through sand/peat putting greens.

Dislodgeable residues followed the same trend as the volatility results, with measured losses decreasing in the order trichlorfon (5.7% first day) > isazophos (5.5% first day) > triadimefon (2.4% first day) > MCPP (0.9% first day). The data generated in this study is being used in computer simulation models to assess possible hazards associated with dermal or inhalation exposures.

University of Florida researchers (Snyder et al.) also have attempted to determine the potential for human contact with turf applied pesticides. The study focuses on the dislodgeability of chlorpyriphos and isazophos onto materials such as cotton, polyester and leather (wet and dry). After the pesticide application, the bermudagrass foliage was irrigated. A day later, pressure was applied at three rates of 5, 10 and 20 kPa (0.7, 1.4, 2.8 psi) to cause dislodging of any foliar residues onto metal plates wrapped with one of the different receptor materials (cotton, polyester, and leather). In general, very little pesticide was dislodged by any of the treatments (much less than 1%). However, all three treatment factors (material, pressure, and moisture) significantly affected the quantity of chlorpyriphos dislodged, while only pressure and moisture affected the quantity of isazophos dislodged. Moist cloth dislodged more pesticide than dry cloth, more pesticide was dislodged at higher pressures, and wet cotton generally dislodged more pesticide than wet polyester.

Introduction

The purpose of these research studies is to evaluate valid alternative methods of pest control for use in integrated turf management systems. Projects investigate alternative pest control methods that include:

- Biological control
- Nonchemical control including cultural and mechanical practices
- Allelopathy
- Selection and breeding for pest resistance
- Ecological balance of turfgrass species
- Application of integrated turf management practices utilizing IPM and low cultural inputs

University of California, Riverside

Investigation of Turf Disease Decline for Potential Development of Biological Control Methods - Dr. William L. Casale and Dr. Howard D. Ohr

In response to environmental concerns and increasing restrictions on the use of chemical pesticides, alternative disease control methods must be developed to reduce our reliance on these materials. Biocontrol of plant disease through the use of "beneficial" microorganisms that are antagonists of disease-causing microorganisms is one such alternative. Since March 1991, sites where disease has declined naturally were investigated for potential biocontrol agents. The disease decline at these sites may be due to increased activity of indigenous microorganisms antagonistic to the pathogen.

A total of 147 microbial organims were isolated from a UCR bermudagrass plot showing decline of spring dead spot caused by *Leptosphaeria korrae*. Disease had spread sufficiently so that green, symptomless patches were obvious in the center of brown, diseased areas; hence, a comparison of microbial profiles from each of these areas could be performed. Among this collection are 41 bacteria and 19 fungi which inhibited the growth of *Sclerotium rolfsii* (cause of southern blight) by antibiosis and 6 fungi that parasitized *S. rolfsii*. Growth of *Rhizoctonia solani* (cause of brown patch) was inhibited by 25 bacteria and 26 fungi from the collection. At the time of this report, tests with *L. korrae* were not completed.

In greenhouse experiments, two bacterial isolates, JT78 and JT80, were most effective at reducing disease caused by *S. rolfsii* and *R. solani* in perennial rye. No detrimental effects were observed on plants by these biocontrol agents, even when applied at high concentrations. Field testing the potential of biocontrol agents was initiated at two bermudagrass plots infected with *L. korrae* and results are pending.

Identification of disease decline sites in California, studies to determine the disease-suppressiveness of turf samples from these sites, and a comparison of virulence of pathogens from these sites are continuing.

University of Florida

Pathogenicity and Biological Control of Gaeumannomyces-like Fungi - Dr. Monica Elliott

The two objectives of this project are to: 1) develop a model system for determining the relationship between melanization of fungal structures and pathogenicity (ability to cause disease) of *Gaeumannomyces* species and related fungi, and 2) determine the biological control potential of non-pathogenic mutant strains of *Gaeumannomyces* fungi for control of turfgrass patch diseases.

At least six turfgrass patch diseases are caused by soil borne fungi with dark-pigmented (melanized) hyphae and an ectotrophic growth habit on roots. These diseases include summer patch and necrotic ring spot of Kentucky bluegrass, take-all patch of bentgrass, spring dead spot and bermudagrass decline of bermudagrass, and take-all root rot of St. Augustinegrass. *Gaeumannomyces graminis* var. *graminis* is associated with the diseases on bermudagrass and St. Augustinegrass grown in the southern United States.

All of these fungi are 'ectomycorrhizal' which means they colonize roots, and therefore, move with the roots. For vegetatively-propagated turfgrass, the pathogen, if present in the sod fields, will be moved with the turfgrass to the new planting location. One method for control would be to introduce a biological control agent into the new planting location prior to planting. An organism that could occupy the same niche as the pathogen would be a viable candidate for biological control. One such group of organisms are mutants of the pathogens that have been rendered non-pathogenic.

DHN (1,8-dihydroxynaphthalene) melanin plays an important role in the fungal cell wall. Inhibition of the production of DHN melanin was demonstrated to be a disease control method, primarily with the plant pathogens *Pyricularia oryzae* and *Colletotrichum* spp. Compounds which inhibit DHN melanin were evaluated in the laboratory for their ability to inhibit the growth of the fungi and to inhibit disease expression. The results indicate that the melanin in *G. graminis* var. *graminis*, *G. incrustans* and *Magnaporthe poae* is DHN melanin. However, inhibition of melanin production did not appear to inhibit their ability to cause disease.

A total of 170 "presumed" mutants of parent strain *G. g. graminis* FL-39 were obtained, primarily using the mutagen N-methyl-N-nitro-N-nitrosoguanidine (MNNG). Among these mutants, 135 were still as pathogenic *in vitro* as the parent FL-39 strain. Two mutants were not pathogenic, seven were intermediate in pathogenicity and two were slightly less pathogenic than the parent strain. All of the non-pathogenicand intermediate-pathogenic mutants had also lost the ability to consistently produce perithecia.

Fifteen mutants of FL-39 have been selected for testing *in vitro*. These are currently being grown on sterile ryegrass seed for use as inoculum sources. All fifteen isolates have been stable in storage and are growing as rapidly on the ryegrass seed as the parent strain. This inoculum will be used in three different methods for evaluation of biological control activity: 1) Simultaneous inoculation of sterilized topsoil mix with a mutant and a pathogenic strain of *G. g. graminis* prior to planting with pathogen-free bermudagrass sprigs, 2) Inoculation of sterilized topsoil mix with a mutant two weeks prior to infestation with a pathogenic strain and planting with pathogen-free bermudagrass sprigs, and 3) Inoculation of sterilized topsoil mix with a mutant followed by planting *G. g. graminis* infected bermudagrass plants. The results from this study will determine the effectiveness of using mutants strains of turf pathogens as alternative pest management methods.

Cornell University

Microbial Basis of Disease Suppression in Composts Applied to Golf Course Turf - Dr. Eric B. Nelson

The overall goal of this project is to develop more effective biological control strategies with compost-based organic fertilizers by understanding the microbial ecology of disease-suppressive composts. In particular, we hope to understand the microbiology to help predict disease-suppressive properties of composts and discover an assemblage of beneficial microorganisms useful in the development of microbial fungicides for turfgrass disease control.

The specific objectives of our study are to 1) determine the spectrum of turfgrass pathogens suppressed by compost applications, 2) establish relationships between overall microbial activity, microbial biomass, and disease suppression in composts, 3) identify microorganisms from suppressive composts that are capable of imparting disease suppressive properties to conducive composts or those rendered conducive by heat treatment, and 4) determine the fate of compost derived antagonists in golf course putting greens following application of individual antagonists and composts fortified with these antagonists.

The suppressiveness of various composts to turfgrass disease caused by two different *Pythium* species and *Typhula incarnata* were established. In field studies, some composts are as effective as standard fungicides in suppressing *Pythium* root rot and *Typhula* blight on creeping bentgrass putting greens.

Laboratory studies have focussed on *Pythium* incited disease of creeping bentgrass. Disease suppression by some composts was a result of microbial activity, whereas suppression in other composts was due to non-microbiological factors. In general, immature composts (less than 1 yr old) were less suppressive to *Pythium* than mature composts (greater than 1.5 yr old). Sterilization of some composts eliminated disease-suppressive properties. These results further indicate a microbiological nature to disease suppression in these composts. In examining a number of suppressive and conducive composts, a direct relationship between microbial activity and disease suppression was established.

Over the past year, efforts were focussed on recovering specific isolates of bacteria, fungi, and actinomycetes from suppressive composts. Bacteria, fungi, and actinomycetes from over 20 different composts were isolated. Actinomycetes have been the most difficult group to enumerate and purify since they are extremely slow-growing and cultures can be easily contaminated with bacteria and fungi. A triple layer agar technique was employed to better recover antibiotic producing actinomycetes. Over 100 strains of actinomycetes are currently being evaluated for their disease-suppressive properties.

Currently, the fungal and bacterial populations from composts are being characterized and screened for disease suppression. Through successful refinement of the microbial biomass assay, repeatable standard curves from both inorganic phosphate and glycerol phosphate can be generated. During the first half of 1993, over 25 different materials will be assessed for levels of biomass and activity to determine whether this method will be suitable predicting disease suppressive properties of composts.

Iowa State University

Potential for Physiological Management of Symptom Expression by Turfgrass Infected by Bipolaris sorokiniana - Dr. Clinton F. Hodges

Ethylene is generated inside the leaves of *Poa pratensis* in response to infection by *Bipolaris sorokiniana* and contributes substantially to the loss of chlorophyll from the infected leaves. This research project was initiated to determine if the ethylene, or its mode of action, can be manipulated to prevent the loss of chlorophyll in infected leaves and prevent yellowing. Prevention of ethylene induced yellowing could result in the control of symptom expression, specifically yellowing of infected turf, independent of the infection. This could reduce use of fungicides and provide a new approach to disease management.

Research conducted in the last year has concentrated on decreasing ethylene in infected leaves by applying ethylene inhibiting substances to roots of inoculated plants. The following materials have been evaluated for their effectiveness when applied to the soil:

- Aminooxyacetic Acid (AOA)
- Aminoisobutyric Acid (AIBA)
- Benzoic Acid (BNZ)
- Canaline (CAN)
- Carbonyl Cyanide m-Chlorophyenylhydrazone (CCCP)
- Cobalt Chloride (COCL)
- Propyl Gallate (PGA)

Ethylene in healthy leaves ranged from 276 to 321 $\mu L\ L^{-1}$. Ethylene within inoculated leaves increased after 24 hours, peaked at 48 hours (1476 $\mu\ L\ L^{-1}$), and then declined at 72 hours and 96 hours. CAN, AOA, CCCP, and PGA applied to roots reduced leaf ethylene in response to infection.

Of the materials that decreased ethylene, only CAN and AOA prevented substantial loss of chlorophyll. Inoculated leaves of plants treated with CAN and AOA retained 74 and 80 percent of their chlorophyll, respectively. Preliminary results from leaf treatments with CAN and AOA show a greater decrease in the surge of ethylene associated with infection than that achieved with soil treatment. Ethylene levels have averaged 30 percent of that in inoculated controls with as much as a 91 percent retention of chlorophyll.

These observations suggest that manipulation of symptom expression in this host-pathogen interaction (and perhaps others) is feasible. Our 1993, studies will concentrate on the function and control of the senescence processes during pathogenesis. Understanding symptom response at this basic level may help develop new control measures or lead to genetic clues on how to develop resistant varieties.

USDA, Rutgers University, University of California

Biological Control of Turf Pests: Isolation and Evaluation of Nematode and Bacterial Pathogens - Dr. Michael G. Klein, Dr. Randy R. Gaugler and Dr. Harry K. Kaya

The objectives of this project are to obtain new strains and species of nematodes and bacteria, which attack white grub insects and to characterize those with the greatest activity against grub larvae. The current need for better biological control agents for use against grubs, such as the Japanese beetle and masked chafers, creates an opportunity to license promising new pathogens to industries for development and commercialization. This cooperative effort between the U. S. Golf Association and a team of U. S. Department of Agriculture and university scientists in Ohio, New Jersey, and California has generated interest from the media and resulted in increased visibility for the USGA's Environmental Research Program.

During the first two years, more than 125 strains and potential new species of entomopathogenic nematodes (i.e., insect/disease causing) were recovered. Four described species, and several possible new species have been isolated by both Ohio and New Jersey scientists from golf course turf and scarab larvae. Additional strains, and possible new species from the two major genera of nematodes, have been identified from California. Results from field plots in New Jersey and California indicate that recently isolated strains were more effective in controlling Japanese beetle and masked chafer larvae than commercially available nematodes. The greater pathogenicity of the recent isolates may be due to an increase in the presence of the symbiotic, pathogenic bacteria within those nematode strains. In addition, the new nematode isolates have proven useful in molecular biology studies on the taxonomy of entomopathogenic nematodes in the U.S. and Ireland.

Efforts to identify other bacterial pathogens of white grubs have located the organism responsible for causing "amber disease" in New Zealand. These bacteria are commercially available there, but their strains have no effect on white grubs in the United States. Over 35 strains of bacteria were successfully isolated from Ohio, New Jersey, West Virginia, California, Japan and China. Fourteen isolates have been characterized in the same genus as the New Zealand bacteria. Feeding tests with those strains have been initiated against Japanese beetle larvae in the laboratory. Additional tests to identify recently isolated bacteria are underway.

Major emphasis during the next year will be to establish the identity and pathogenicity of nematode and bacterial isolates already obtained as a result of this project. In addition, efforts to obtain new isolates of both nematodes and bacteria from infected white grubs in golf course turf in Ohio, California, and New Jersey will continue. The effectiveness of all isolates against white grubs will be established in order to determine their commercial value.

University of Kentucky

Damaged Thresholds, Risk Assessment, and Environmentally Compatible Management Tactics for White Grub Pests of Turfgrass - Dr. Daniel A. Potter and Dr. Andrew J. Powell

The objectives of this project are to: 1) establish damage thresholds for root feeding white grubs on cool season turfgrasses, 2) evaluate the compatibility of turfgrass pesticides with beneficial invertebrates, 3) field test a pheromone-based system for predicting white grub densities, and 4) evaluate the potential for reducing white grub populations through non-chemical, cultural manipulations.

The impact of varying densities of Japanese beetle or masked chafer grubs on root and foliar growth and aesthetic quality of six different turfgrasses was measured in field tests using sunken enclosures and rooting boxes. Grub feeding preferences and tolerance of turf under differing management regimes were also evaluated in field and greenhouse tests. Masked chafer grubs are more damaging than Japanese beetle grubs at equal densities, however, our results show that healthy turf can tolerate at least 20 masked chafer grubs or 30 Japanese beetle grubs per ft^2 before showing visible damage.

Kentucky bluegrass is relatively susceptible, and tall fescue is relatively tolerant of grub damage. The tall fescue endophyte does not confer resistance to grubs of either species. Fall irrigation increased rooting strength and hastened recovery of turf from grub damage. Spring fertilization did not affect expression of grub damage the following fall. Japanese beetle grubs showed significant preference for perennial ryegrass, whereas masked chafer grubs showed no preference among grasses. Presence of one grub species did not affect the distribution of the other. These studies indicate that damage thresholds for white grubs are higher than previously thought, and that remedial irrigation should mask the injury from all but very severe infestations.

The impact of pesticides and growth regulators on earthworm populations was evaluated in two field tests conducted in spring and fall 1992. Of more than 40 products tested so far, only two fungicides (benomyl and thiophanate-methyl) and five insecticides (bendiocarb, carbaryl, ethoprop, diazinon, and fonofos) had significant impact on earthworms. This shows that most of the pesticides and related products used on golf courses are compatible with these beneficial elements of the soil fauna.

Studies were initiated in 1992 to compare the abundance and diversity of predatory insects and spiders in meadows, lawns, and golf course roughs. Preliminary sorting of samples suggests that golf courses support populations of predators at levels similar to those found in lawns and meadows. Feeding studies confirmed that many of the more abundant predators readily consume eggs and larvae of turfgrass pests.

Efforts to identify the sex pheromone of masked chafers were bolstered by initiation of collaboration with Dr. J. Meinwals, one of the preeminent natural products chemists in the world. While collecting virgin females for analysis, we observed and then confirmed experimentally that the adult male beetles are attracted to both sexes of grubs. Presence of a chemical attractant in grubs was confirmed experimentally. This is the first report of attraction of adults to the larval stage for any insect species. This finding has considerable basic significance because it sheds insight on how sex pheromone communication systems may evolve. In practical terms, it extends the period during which we can collect and extract crude pheromone for chemical analysis. Identification of the attraction will increase the practicality of using traps to assess the risk of grub damage to particular sites.

Soil pH, fertilization, watering, soil compaction, and mowing height were manipulated in large field plots to determine how they would affect choice of egg-laying sites and subsequent densities of grubs. Even in this wet year, female Japanese beetle and masked chafer beetles were attracted to irrigated turf, resulting in much higher grub densities. We found about an 80 percent reduction in masked chafer grubs in plots treated with aluminum sulfate, and about a 50 percent reduction in high-mown turf. Fertilization neither increased nor decreased grubs. Soil compaction did not affect subsequent grub densities, and use of a heavy (5000 lb) roller to crush the active grubs was not effective.

Introduction

The purpose of these projects is to document and quantify the influence of golf courses on people, other biological organisms, and environmental factors. The studies include research pertaining to the influence of golf courses on:

- Local soil and climate, pollutants that affect air quality, soil stabilization and watershed management, and noise modification
- Biological diversity of flora and fauna in urban and urban-agriculture fringe areas
- Psychological and physical well-being of people, and the importance of landscape aesthetics to humans

Spectrum Research, Inc.

Golf Course Management and Construction: Environmental Issues - Dr. James C. Balogh and Dr. William J. Walker

Golf Course Management and Construction: Environmental Issues was published by Lewis Publishers, Inc. in June 1992. The book presents a comprehensive summary and assessment of the technical and scientific research on the environmental effects of turfgrass management and, to a smaller extent, golf course construction. The book is intended as an introduction to the concepts of the non-point source environmental impacts of turfgrass management for turfgrass scientists and specialists, landscape and golf course architects, developers of turfgrass systems and golf courses, golf course superintendents, environmental scientists, and land use regulators.

The book is organized into eight chapters. The introduction provides an overview and historical perspective regarding turfgrass management and environmental quality. The second chapter discusses the relationship of turfgrass management to the critical issues of water resources. This chapter focuses on the issues of water use, water quality, soil and water conservation, and movement within the hydrological cycle. Chapters three and four provide a comprehensive scientific review and assessment of the literature regarding the environmental effects of nutrient and pest management practices. The fifth chapter provides an introduction to concepts necessary for development of integrated management systems for turfgrass. Chapter six covers the direct and indirect effects of golf course management and construction on wildlife and aquatic organisms. The seventh chapter is an introduction to the critical issues of conservation and protection of wetlands which has emerged as a critical environmental concern of the 1990's. Chapter eight contains tables of aquatic and terrestrial toxicity tests related to the effect of chemicals used for turfgrass management.

Each of the chapters includes a section on research and information needed to resolve the issues surrounding the positive and potentially adverse effects of turfgrass management. In less than one year *Golf Course Management and Construction: Environmental Issues* has sold nearly 2,000 copies. This comprehensive review has received numerous positive comments and is necessary reading for those heavily involved with the environmental issues confronting golf courses.

Texas A&M University

Quantification and Validation of the Beneficial Contributions of Golf Course Turfgrasses - Dr. James B. Beard and Dr. Robert L. Green

The value of most industries is measured by income derived from products or services. However, this is not entirely germane to a major portion of the diverse turfgrass industry. Rather, the value encompasses a range of beneficial contributions to our environment and quality-of-life that are not easily quantified in monetary terms. Thus, the objective of this study was to conduct a detailed assessment of the research literature to obtain a valid scientific base source of information documenting the benefits of turfgrasses.

Over 400 scientific references were identified, obtained, and assessed. Some were difficult to obtain as they were in obscure reports. Much time was spent in conducting over 170 personal phone calls with individuals involved in the actual research. In addition, much time was devoted to assessments of the scientific soundness of the research, including the experimental methodology, actual conduct of the experiments, and valid interpretation of the results. An extremely diverse range of technical subjects were addressed. Scientists knowledgeable in these individual specialties were contacted to confirm the validity of the research papers being considered for citation.

A total of 116 scientific papers were identified as most germane to the objectives of this project. The principle charge from the USGA Environmental Research Committee was to develop a scientifically based paper on the benefits of turfgrasses targeted for publication in a peer reviewed scientific journal. The paper was completed and reviewed by fourteen key world-respected scientists representing the broad range of technical subjects addressed. It also was reviewed by Texas Agricultural Experiment Station personnel, approved for publication and submitted to the Journal of Environmental Quality.

The topic areas include: (a) turfgrass evolution; (b) history of turf use; (c) turfgrass functional benefits including soil erosion control and dust stabilization, ground water recharge and surface water quality, organic chemical decomposition, carbon sink, heat dissipation, noise abatement, glare reduction, decreased noxious pests, allergy related problems, safety in vehicle operation, security for vital installations, and wildlife habitat; (d) turfgrass recreational benefits; (e) turfgrass aesthetic benefits including improved mental health via a positive therapeutic impact and contributions to social harmony and improved occupational productivity; (f) contemporary issues such as water conservation and ground surface water quality preservation as related to pesticide and fertilizer use.

This has been a rewarding and enlightening project and a new perspective has evolved concerning the environmental issues challenging the golf courses. This position paper, and other USGA projects, are needed first steps to address environmental issues. However, the lasting solution will be achieved from the golf course industry and environmental groups working together to achieve common goals and objectives.

The Earth Fund

On Course with Nature - Dr. Donald F. Harker

This project has adapted information on ecoregions across the United States for use in naturalizing landscapes around golf courses. The result of this effort will be the *Landscape Restoration Handbook* which will be published in June 1993. By increasing the natural areas around the golf course, it is hoped to increase or preserve wildlife habitat.

Earth Fund researchers look at golf courses as valuable green space within the urban environment. Golf courses, however, are not regularly cited in scientific literature concerning wildlife habitat, and more often receive negative attention in popular press. This project surveyed the literature on natural areas and established woodland size, vegetation structure, and other information to encourage wildlife usage of golf courses. The United States is already divided into natural ecoregions and the book developed from the project describes how to recreate or manage the natural vegetation on the site.

Lists of native plant species and nurseries in the United States that produce these materials was incorporated into the book. The landscape side of the problem, or the "how to do it" principles, are a major portion of the book. Careful attention to recommendations on adapted plant materials for a region was emphasized. A detailed map of the United States indicating the natural ecoregions and plant communities was developed and will be included in the book. Landscape architects and horticulturalists can use this map and then go to a nursery to select suggested plant species. Currently, native plant species do not have something similar to this approach, and the project will help a great deal to meet this need.

From an urban planning perspective, the book could help develop scenarios for natural corridors through urban areas by linking golf courses, parks, and larger tracts of land. The concept of 'sustainable development' and 'quality of life' also were covered. The *Landscape Restoration Handbook* will be available in June 1993.

The Institute of Wildlife and Environmental Toxicology

The Effects of Golf Course Activities on Wildlife - Dr. Ronald J. Kendall

The Institute of Wildlife and Environmental Toxicology (TIWET) at Clemson University has conducted numerous studies on the environmental effects of pesticides used on golf courses. TIWET, with USGA funding, initiated research in golf course management practices to institute environmentally sound approaches based on knowledge of chemical use, fate and effect. Resulting information will aid in the development golf course management practices that provide satisfactory playing surfaces, without damage to the environment.

The basic objective of the project was to understand the "golf course ecosystem." This includes an understanding of how birds, fish, and plants respond to golf course chemical inputs, as well as pesticide and nutrient behavior in water, soil, and sediments. This information will be integrated into an ecological risk assessment which can be applied, initially, to the Ocean Course at Kiawah Island and potentially, to a wider distribution of courses.

The golf course research group consists of seven graduate students and five faculty members from the Department of Environmental Toxicology and TIWET at Clemson University. The pilot study on the Ocean Course, Kiawah Island, began in July, 1991. This investigation focused on two areas: 1) developing a thorough water sampling program to measure the quantity of fertilizers and pesticides reaching adjacent marshes; and 2) assessing the potential for exposure of wildlife on the Ocean Course and adjacent habitats.

The development of Kiawah was conducted with environmental foresight, resulting in a residential and resort community endowed with diverse habitat and abundant wildlife. The Ocean Course, constructed with an innovative drainage system that captures runoff from rainfall and irrigation, is situated in a sensitive ecosystem of sand dunes and tidal marsh. Chemicals used on the course are deterred from entering adjacent wetlands and the water can be recycled.

TIWET efforts have concentrated on gathering background information on the Ocean Course and on substantiating irrigation and chemical application procedures. Maps and diagrams were developed and used to describe the flow of irrigation and drainage water on the course. Turf management practices and pesticides used on the Ocean Course were documented. Chemical application records were collated and the irrigation schedule was recorded. Water samples have been collected for preliminary analysis of fertilizer and pesticide residues.

Texas A&M University

Human Benefits of Golf Course Views: Emotional Well-Being, Stress and Performance - Dr. Louis G. Tassinary and Dr. Roger S. Ulrich

While golf courses are an important type of land use in most cities and suburban areas, there is little scientific evidence regarding the human benefits that golf courses make possible. More specifically, there is virtually no sound, convincing research regarding the "influence of golf courses on the psychological and physical well-being of people." The absence of research on these issues is not a problem for the avid golfer, for whom the benefits of golf courses and the game are intuitively self-evident. The great majority of Americans, however, are not golfers, and accordingly lack the direct experience that is probably necessary for an intuitive appreciation of the benefits of golf courses and the game.

The lack of research on golf course benefits can be a major problem both from the standpoint of communicating or marketing the benefits of the game to the non-golfing public, and/or conveying the benefits of a proposed golf course to either a planning commission, a zoning board, a city council, or a group of environmentalists. The reality is that intuitively-based arguments about the human benefits of golf courses, however commonsensical to golfers, carry little or no weight in the face of the more publicized or tangibly documented issues such as pesticide and nutrient runoff, consumption of scarce water resources in semi-arid areas, or membership polices based on racial or ethnic criteria.

A major feature of the two proposed studies is the emphasis placed on state-of-the-art *physiological* and *behavioral* measurement techniques, in combination with self-report techniques, such as questionnaires, for examining the effects of golf courses on human well-being and cognitive performance.

The initial plan was to conduct two studies. The main objective of the first study was to identify and measure the physiological and emotional effects of off-site views of golf courses and compare these effects with those resulting from viewing other common types of landscapes. The main objective of the second study was to identify and measure the effects of viewing golf courses on the performance of cognitive tasks relevant to productivity in the workplace.

Performance on these tasks will be diagnostic of our capacity to either monitor or reject incoming information and to either analyze or synthesize diverse information. For example, a significant part of the project will focus on whether viewing a golf course elicits a positive mood, that in turn enhances performance on tasks related to creative thinking. Video footage has been taken in the Houston, San Antonio, Austin, Dallas/Fort Worth, and Sam Houston Forest areas. On the basis of this footage, a small group of candidate sites was selected from a large number of potential sites within each environmental category and videotaping was completed in the fall of 1992. The raw video footage for the first study has been previewed and cataloged, and the final editing was completed in January, 1993.

A systematic search of the mood induction literature over the past 20 years (>200 articles) using a number of electronic data bases and bound indexes was completed. As a result of this search, and taking into account the results from an informal pilot study (10 subjects), a music-based mood induction procedure was chosen in place of a verbal self-instructional procedure to elicit both the positive and negative moods for the comparison conditions in the second study.

Seventy-two color slides were made from digitized frames of our video material and pretested in a formal study completed last fall (100 subjects). The results of this study have allowed us to pick clearly positive and clearly negative video segments that represent golf course, forest, and urban environments for the second study. All of the necessary computer, data acquisition, physiological recording, and audiovisual equipment has been purchased, tested, and installed.

The research scientist on the project (Russ Parsons, Ph.D) has completed formal training in the software environment that will be used in the lab and has written and debugged the core of the computer programs required for experimental data acquisition and control. The results of our preliminary experiments were presented in October 1992 at the annual meeting of the Society for Experimental Social Psychology.

The anticipated benefits of the research will include: 1) the potential positive consequences of golf course location for off-site users will be identified, assessed, and made accessible for practitioners involved in land use decisions; 2) a precedent will be established for the training of graduate students in landscape architecture on the indirect health consequences of golf course design and location; 3) peer reviewed publications in established scientific journals; and 4) continued theory development in an ongoing basic research effort by the investigators to more fully characterize the dynamic relationship between humankind and the natural landscape.