

Analysis Of Environmental And Health Effects Of Pesticides On Golf Courses

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Abstract— Over the past 30 years there have been many studies and concerns about the environmental and health effects of pesticides used on golf courses. Their exposure to millions of people each year has attracted attention to any potential environmental and health risks that come with using pesticides. On the environmental side, this literature review found that pesticide levels in runoff and sediment samples were within USDA regulations but harmed the biota around golf courses. Many of these chemicals persisted in the environment long after application, leading to prolonged risks to ecosystems and human health. On the health side, chemicals like Chordane, Dichlorodiphenyltrichloroethane (DDT), and Lindane were found to be linked to Non-Hodgkin's Lymphoma. Overall, this literature review found that current environmental regulations are inadequate and additional measures are necessary to mitigate the risks that come with using pesticides in the turf management industry.

Keywords— Pesticides; Golf courses; Turf management; Environmental impact; Health effects; Occupational exposure.

Introduction

Pesticides are an integral part of golf course turf maintenance. When blades of grass are cut short, it leaves them susceptible to disease and pests, thus necessitating pesticides or other methods of keeping the grass healthy (Turner et al., 2018). A key difference that sets golf courses apart from other agricultural settings is their year-round maintenance schedule, which results in frequent and repeated applications of a wide range of chemical classes, including fungicides, herbicides, and insecticides (Doherty et al., 2020). This ongoing chemical exposure creates potential for long-term health risks amongst workers and players and has adverse environmental consequences, particularly in surrounding ecosystems (Ahmad et al., 2023).

One of the most widely used pesticides in golf course turf management is chlorothalonil, a fungicide applied to control fungal diseases that affect turfgrass aesthetics and feel (U.S. EPA, 2006). Chlorothalonil has been classified by regulatory agencies in group 2B which is a possible carcinogen. It is known for its persistence in the environment, ability to volatilize into the air, and potential to contaminate groundwater and surface water (U.S. EPA, 2006). When Chlorothalonil was tested on laboratory animals, evidence of kidney and stomach cancer was found (Kross et al., 1996; Beard & Green, 1994). In addition to this, Chlorothalonil's ability to spread and persist in the environment presents as a challenge for greenspace workers like gardeners and greenkeepers who should protect themselves from exposure by skin and inhalation (Kross et al., 1996; Beard & Green, 1994).

Additionally, environmental monitoring has revealed that pesticides and nutrients from fertilizers on golf courses can leach into nearby aquatic systems, collect in sediments, and persist in the soil from 100 to well over 1000 days after application (U.S. EPA, 2008). While some studies such as the Long-Term Evaluation of Reduced Chemical Pesticide Management of Golf Course Putting Turf (Grant et al., 2000), report that pesticide levels

remain below regulatory standards, other reports including the Quantitative Analysis of Over 20 Years of Golf Course Monitoring Studies (Baris et al., 2010), elevated phosphorus concentrations, which contribute to eutrophication and the subsequent deoxygenation of aquatic ecosystems. The improper handling of pesticide runoff can harm aquatic biota. 2001, the runoff from a golf course killed all the eels, fish, and crawfish of two streams that led into the Potomac River in Washington D.C. (Beyond Pesticides, 2001).

This literature review aims to examine and synthesize the current body of evidence that surrounds the health risks to golf course workers and the long term environmental effects of pesticide use on golf courses. By looking into both the epidemiological and environmental studies, this review highlights an overall consensus on the current state of health and environmental risk that comes with using pesticides in the golf turf management, while also addressing any key limitations with existing research.

I. Methods

This review searched for studies on search sites (Pubmed, Columbia Review, Google Scholar) for studies that involve golf course workers—such as superintendents and maintenance staff—or that focus on environmental sampling related to pesticide use on golf courses. Eligible research must examine health effects, including cancer, neurological disorders, or respiratory issues, or explore environmental outcomes such as pesticide runoff, sediment contamination, or air volatilization. Accepted sources include peer-reviewed primary research, systematic reviews, toxicological assessments, epidemiological studies, and reports from government agencies or NGOs. Excluded from consideration are opinion pieces, news articles, and other non-scientific sources, as well as case studies lacking measurable data, research unrelated to pesticide use on golf courses, and studies that do not address either human health or environmental impacts.

II. Search Strategy

A structured literature search was conducted using the following academic databases and platforms: PubMed, and Google Scholar. Searches were limited to English language sources after 1970. Additional scientific papers were found through reference lists of key studies included in the reviews. The initial search used the primary term “golf course pesticides.” Secondary terms included: “occupational pesticide exposure”, “golf course workers”, “cancer”, “neurological disorders”, “chlorothalonil”, “inhalation risk”, “green space workers” for the health space aspect of this paper while the terms “chemical runoff”, “pesticide volatilization”, “groundwater contamination”, “sediment toxicity”, “turfgrass pesticide use” were used to search for sources in the environmental aspect of this paper.

A total of 8 studies and one research paper met the criteria and were reviewed in detail. The findings were grouped into two categories: Health risks to golf course workers and environmental impacts of pesticide use on and around golf courses.

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epidemiological studies, and reports from government agencies or NGOs. Excluded from consideration are opinion pieces, news articles, and other non-scientific sources, as well as case studies lacking measurable data, research unrelated to pesticide use on golf courses, and studies that do not address either human health or environmental impacts.

III. Health Risks to Golf Course Workers

Five studies fit our criteria and focused on the health risks that pesticides posed on golf course workers with a focus on cancer and chronic neurological conditions (Table 1).

The Proportionate Mortality Study of Golf Course Superintendents (Kross et al., 1996) analyzed 686 death certificates of white Golf Course Superintendents Association of America (GCSAA) members and reported elevated cancer and nervous system disease rates compared to national averages for white males. Although this study found a link between long-term pesticide exposure and increased mortality risk, it did not account for confounding variables such as family history or smoking status due to its main source of data coming from death certificates.

The systematic review by Beard and Green (1994) analyzed health outcomes across various greenspace occupations, including greenspace workers, horticulturists, and gardeners. The review found an increased risk of cancer and neurological conditions for workers exposed to pesticides but included studies that lacked controls for confounding variables, limiting the confidence in the conclusions [Occupational Pesticide Review Exposure Review].

The Volatilization of Pesticides from Golf Courses study (Wong & Haith, 2013) presents a different perspective by exploring inhalation risks from airborne pesticide residues, with a focus on chlorothalonil, a fungicide commonly used on golf courses. The study demonstrated that pesticides can evaporate into the surrounding atmosphere after application and reach dangerous concentrations when inhaling, especially for workers performing maintenance shortly after spraying. While the study concentrated on vapor exposure, it acknowledged that runoff, leaching, and photodegradation were not considered in the risk model. Collectively, these studies support growing concern that chronic, low-level pesticide exposure—especially through dermal contact and inhalation—may contribute to long-term health problems in golf course workers. Although existing evidence is suggestive, more controlled studies are needed to determine specific health outcomes.

The meta-analysis by Lerro et al. (2015), titled "Insecticide Use and Risk of Non-Hodgkin Lymphoma Subtypes: A Subset Meta-analysis of the North American Pooled Project," analyzes 1,690 non-Hodgkin lymphoma (NHL) cases and 5,131 controls to evaluate how insecticides correlate to overall NHL. This study found that Lindane, Chlordane, DDT, and Pyrethrum all had strong links to NHL with a positive association between risk and duration of time exposed. Not all pesticides carry uniform risk but evidence of attack-specific insecticides targeting NHL subtypes such as Follicular Lymphoma, Diffuse large B-cell lymphoma, and small lymphocytic lymphoma. This variation of the effects different insecticides have for different subtypes of NHL highlights the importance of evaluating pesticide exposure for subtype specific NHL and other forms of cancer rather than treating them as a uniform disease [A subset meta-analysis of the North American Pooled Project].

IV. Health Risk Discussion

The pesticide use on golf courses is a unique risk to human health as many pesticides such as chlorothalonil, glyphosate, and chlorpyrifos are widely used year round. Regarding worker health, findings from both the Proportionate Mortality Study (Kross et al., 1996) and the systematic review of greenspace workers by Beard and Green (1994) suggest a potential link between chronic exposure of pesticides and elevated rates of cancer and neurological disorders. Although data quality varies and confounding variables such as smoking status or lifestyle were not discussed, the data overall supports the correlation between exposure to pesticides and elevated mortality risk. The volatilization study by Wong and Haith (2013) highlights inhalation as a significant, yet often overlooked, method of exposure, particularly following pesticide application of chemicals like chlorothalonil. The meta-analysis by Lerro et al. (2015), titled "Insecticide Use and Risk of Non-Hodgkin Lymphoma Subtypes: A Subset Meta-analysis of the North American Pooled Project," supported the link between insecticides such as Lindane, Chlordane, DDT, and Pyrethrum and NHL and its subtypes. This study supported the need for further research on the correlation between pesticides and subtypes of cancers. Overall, data from these 5 studies supports the addition or improvement of safety measures for greenspace workers in order to mitigate the cancer risks that pesticides present.

V. Environmental Impacts of Pesticide Use on Golf Courses

Five studies fit our criteria and focused on the environmental risks that pesticides posed on the environments around golf courses (Table 1).

Numerous studies have investigated how pesticide use on golf courses affects the surrounding environment, with a focus on runoff, sediment contamination, volatilization, and nutrient loading. While pesticide concentrations often fall below legal thresholds, the cumulative and long-term ecological risks—particularly to water bodies and aquatic organisms—remain an area of concern.

The Sediment Chemical Composition and Toxicology Study (DeLorenzo et al., 2001) assessed pesticide and metal contamination in sediments collected from coastal golf courses in Florida. Using bioassays with aquatic species, including *Hyalella azteca* and grass shrimp embryos, the study found that while contamination from golf course runoff was detectable, it did not exceed regulatory toxicity limits. The authors noted, however, that results might differ with alternative test species or sediment profiles, indicating a possible underestimation of the harm that pesticides would do to the ecosystem [Sediment Toxicology Study].

A Quantitative Analysis of Over 20 Years of Golf Course Monitoring Studies (Baris et al., 2010) compiled 38,827 water quality samples from U.S. and Canadian golf courses. While pesticide residues in surface water were generally low, the study found excessive levels of phosphorus, a common turf nutrient, in many samples. The presence of elevated phosphorus raises concerns about eutrophication and the long-term ecological health of nearby aquatic systems [20-Year Monitoring Study].

The Volatilization of Pesticides Study (Wong & Haith, 2013) modeled how chemicals, particularly chlorothalonil, evaporate into the air after application. Using volatilization flux and vapor concentration equations, the study showed that significant quantities of pesticides could disperse into the atmosphere and travel beyond the application area, potentially

affecting neighboring environments. However, other paths for the pesticides to escape such as runoff and degradation were not included into the models, which may limit the scope of its conclusions [Volatilization Study].

The Toxic Fairways Report (New York State Attorney General, 1995), which reviewed pesticide use across 52 golf courses in Long Island, identified widespread application of high-risk and potentially carcinogenic pesticides. The report highlighted the leaching potential of certain chemicals and their ability to infiltrate groundwater sources, posing risks to both ecosystems and public drinking water supplies. While not a peer-reviewed academic study, the report raised important regulatory concerns and called for tighter environmental oversight [Toxic Fairways Report].

In the Ecological Risk Assessment Study by Garrison et al. (2014), researchers used 36 years of weather data from nine U.S. cities to predict pesticide runoff from turfgrass into ponds. Of the 37 pesticides evaluated, 32 remained below ecological safety thresholds, but five exceeded limits under certain weather and application scenarios. The findings emphasize that geographic and meteorological variability can significantly affect pesticide behavior and localized environmental risks.

A U.S.–Europe Comparative Study (Turner et al., 2018) analyzed application data from eight regions and assessed ecological risks using hazard quotient models. While most pesticide concentrations remained within acceptable regulatory limits, the study found that fungicides were the greatest ecological risk, even at low concentrations, due to their chronic toxicity to aquatic organisms. It concluded that regional regulations significantly influence the overall environmental burden of golf course pesticide use [U.S.–Europe Risk Analysis Study].

Lastly, a seven-year turfgrass management study conducted at Bethpage State Park in New York (Grant et al., 2000) compared the environmental impact of three pest management systems: Conventional Pest Management (CPM), Integrated Pest Management (IPM), and Best Biological Practices Management (BBPM). CPM relies heavily on routine pesticide applications to ensure maximum turf quality, often without regard for environmental impact. IPM takes a more targeted approach by using pest monitoring, threshold-based treatments, and a combination of chemical and non-chemical methods to reduce pesticide use. BBPM emphasizes biological and cultural controls, such as using pest-resistant turf varieties and promoting healthy soil, to minimize the need for chemical inputs altogether. While CPM provided the highest turf quality, it also resulted in the greatest environmental risk, as measured by the Environmental Impact Quotient (EIQ). In contrast, IPM and BBPM significantly reduced pesticide-related environmental risks—by up to 95% in some years—while still maintaining acceptable turf performance. This study supports the adoption of reduced-chemical management systems as a viable alternative for minimizing ecological harm.

VI. Environmental Risk Discussion

These studies demonstrate that while many golf courses adhere to current safety regulations, pesticide use still poses long-term environmental risks—especially in sensitive ecosystems and under variable climate conditions. Mitigating these impacts will require both strict

application processes and broader implementation of integrated or biological management approaches.

We find a consistent association between pesticide use on golf courses and environmental harm. While pesticide concentrations generally stayed below regulatory thresholds, repeated, year round applications unique to golf course turf management contribute to a cumulative exposure risk for the surrounding environment.

From an environmental perspective, most studies report low concentrations of pesticides in runoff and sediment but include localized areas as potential areas of harm, especially near water bodies. The Sediment Toxicology Study (DeLorenzo et al., 2001) and 20-Year Monitoring Study (Baris et al., 2010) both identified the presence of pesticides without toxicity, but they highlight long-term concerns such as nutrient pollution from phosphorus fertilizers and potential accumulation in organisms over time. The Ecological Risk Assessment Study (Garrison et al., 2014) demonstrated that pesticide runoff remains sensitive to weather variation and factors specific to local areas, complicating risk management strategies.

Moreover, regional differences in regulatory frameworks affect pesticide risk profiles. The U.S.-Europe Comparative Study (Turner et al., 2018) found that stricter regulations in European countries typically resulted in less ecological risks compared to the U.S., especially regarding fungicide use, which was the most ecologically hazardous chemical class. This suggests that strong policies play a critical role in reducing environmental harm.

Finally, the Bethpage State Park long-term study (Grant et al., 2000) supports the potential of Integrated Pest Management (IPM) and Biological Management (BBPM) to significantly reduce environmental pesticide impacts while maintaining turf functionality. However, their implementation is slow, likely due to higher labor costs and unsatisfactory visual turf quality.

Overall, current regulatory limits may underestimate the chronic risks associated with year-round pesticide use on golf courses. Beyond direct exposure to workers, pesticides applied on golf courses can runoff into nearby watersheds, contaminating the water and harming aquatic ecosystems. This runoff can lead to bioaccumulation of the pesticides in aquatic organisms and degrade water quality for surrounding communities. The Review of Pesticides on Aquatic Microorganisms (DeLorenzo et al., 2001) have shown that pesticide residues from golf courses frequently enter nearby bodies of water, contributing to environmental stress and potential harm to the nearby aquatic biota. Therefore, a combination of stricter regulations, improved management systems, and increased worker protection is necessary to mitigate both occupational and environmental impacts.

VII. Future research

As part of this review we recommend that future studies should focus on:

- Long-term, controlled cohort studies evaluating health outcomes in golf course workers;
- More comprehensive assessment of combined exposure pathways (inhalation, dermal, and ingestion);

Site-specific modeling of pesticide runoff and volatilization under varying climatic conditions;

- Evaluating the cost-effectiveness and practicality of reduced-chemical management systems.
- Given the recreational and aesthetic importance of golf courses, sustainable pesticide practices are essential to safeguard worker health and protect surrounding ecosystems.

VIII. Conclusion

Pesticide use on golf courses is a source of occupational health risks for workers and environmental harm, despite compliance with current safety regulations. Evidence suggests that chronic exposure to pesticides such as chlorothalonil, lindane, and DDT may contribute to cancer, neurological disorders, and respiratory risks among golf course workers. Environmentally, repeated applications of pesticides throughout the year can lead to persistent chemical presence in soil, water, and air, with localized impacts on aquatic biota and groundwater resources.

Regulatory differences between regions emphasize the role of policy frameworks in managing pesticide related risks. Implementation of integrated and biological pest management systems prove to be better alternatives in reducing environmental impact without significantly compromising turf quality.

Table 1. Collection of Findings From Papers on Pesticide Risk to Humans

Study Name	Study Location	Sample Description	Study Design	Main Findings	Biases/sh ortcoming s
The Proportionate Mortality Study of Golf Course Superintendents (Kross et al., 1996)	Golf Courses from every state in the U.S.	Deceased white members of GCSAA	Study death certificates of 686 deceased members of GCSAA and comparing the rates of cancer deaths of superintendent with the rest of the country	Cancer and nervous system diseases	The study relied on death certificates which lacked exposure data and had confounding variables such as family history, whether they smoked, and their lifestyle.

Volatilization of Pesticides from Golf Courses study (Wong & Haith, 2013)	United States	Golfers in contact with the chemical while playing golf	Golfers wearing cotton suits were tested after a round of golf on a course that was freshly sprayed with pesticides. 37 pesticides were tested to see if they were present on the suits and if the levels were above or below the safe limit.	Golfers exposed to carcinogenic chemicals but the amounts were too small to be dangerous	Other ways to lose volume such as leaching, runoff, or photodegradation were not considered.
The systematic review by Beard and Green (1994)	Study locations included: United States, Canada, United Kingdom, Denmark, Norway, and France	Between 300 and 20,000 Greenkeepers, gardeners, and horticulturists per study	Studies were referenced with between 300 and 20,000 people in each study. This paper collected data from different studies and compared their results on cancer rates among greenspace workers.	Compares cancer rates between different occupations and genders	Some of the studies mentioned don't account for confounding variables and some of the data seem weak

The meta-analysis by Lerro et al. (2015), titled "Insecticide Use and Risk of Non-Hodgkin Lymphoma Subtypes: A Subset Meta-analysis of the North American Pooled Project"	U.S. (Kansas, Nebraska, Iowa, Minnesota)	6821 People from ages 19 to 30 and older, Medicare listings for people 65 and older, deceased people	Compare 6821 people with NHL with the amount of exposure they had to different chemicals.	Insecticides like Linden, DDT, and Chlordane are strongly associated with subtypes of NHL. The risk of NHL increased with the amount of time exposed to these chemicals.	This study's limitation is that it pooled data from multiple studies and didn't consider if all of these studies had the same case definition and exposure assessment.
The Toxic Fairways Report (New York State Attorney General, 1995)	Long Island New York, U.S.	Anybody in contact with the pesticide including surrounding communities	This study analyzed 52 Long Island golf courses for pesticides used, leaching potential, and discussed potential carcinogens.	Carcinogens and other immediate health effects due to poisoning	This paper lacked scientific peer evaluation and was intended for worst case scenarios. This paper was also biased because it was intended to advocate for limiting pesticide use on golf courses.

Fig. 1 Summary findings of recent papers on human risks from pesticides used on golf courses**Table 2. Collection of Findings from Papers Detailing Pesticide Risk to Environments**

Study Name	Study location	Sample Description	Study size	Study design	Main point	Shortcomings /Biases
The Sediment Chemical Composition and Toxicology Study (DeLorenzo et al., 2001)	Coastal Golf Courses in Florida	Soil samples from bayou were taken within 3 meters of the runoff spot while samples taken from the Santa Rosa Sound were taken within 100 meters of the shore	14 Sampling Stations with 42 Acute and Chronic Bioassays	Sediments were tested for metals and chemicals. Another part of the samples were centrifuged and let to rest for an hour. After the hour, a bioassay was done with hyalella azteca, mysidopsis bahia, Chironomus plumulosus, and grass shrimp embryos	Chemical runoff from the coastal golf course into the surrounding soil is present but the levels aren't dangerous enough to prove anything. The bioassays also showed that the water from the runoff was fine.	The bioassay could show different results if the sediment from another golf course or a different organism was used.
A Quantitative Analysis of Over 20 Years of Golf Course Monitoring	Golf courses throughout American and one in Canada	Golf courses throughout the U.S. submitted test samples of their water.	38,827 samples from surface water and ground	Entries submitted into the database were compared to and	While pesticides are not a big concern in surface water	Does not discuss if there are any changes to safety regulations or standards

Studies (Baris et al., 2010)			water	compared with local/stat e standards for safety	testing, the total phosphor ous amount in the water was concernin g and requires action. This study was made to fill in the data gap in the reliable water quality data.	between America and Canada
The Ecological Risk Assessment Study by Garrison et al. (2014)	9 different locations in the U.S. Albany, NY Atlanta, GA Bismark, ND Columbus, OH Fresno, CA Houston, TX Madison, WI Olympia WA Roswell, NM	36 years of weather data and the resulting dissolved concentration s of pesticide in the pond in the nine locations	Weather data and pesticide runoff data from 9 locations	The data of weather condition s are put into a simulatio n to figure out how much pesticide is left on the grass. This is compared with safe levels of the pesticides .	Out of 37 pesticides tested, 32 stayed below the legal levels but 5 of them were exception s. These could be explained by variations models, scenarios, and input data.	This study was based on assumptions rather than empirical environmenta l sampling which weakened its results. It also didn't consider the combined effects of pesticide mixtures or chronic low- level exposure.
A U.S.- Europe Comparativ	5 regions across the U.S. (Midwest,	The Golf course superintende	Data from 68 courses	Hazard Quotient of	Although pesticides from the	This study was limited by regional

e Study (Turner et al., 2018)	Northeast, east Texas, Florida, Northwest, Southwest) and 3 regions across Europe (Norway, Denmark, Sweden, U.K.)	nts submitted Pesticide application records from the past 3 years within 2016 to 2021	across all 8 locations but only 6 of them had the required 5 responses or more	pesticides are calculated , Calculate Component Weighted Average Hazard Quotient, Calculate Risk to Intensity Quotient	golf courses to other places via waterways, the pesticide concentrations stay below USDA levels. Even though pesticide levels stay below USDA levels they still negatively affect aquatic ecosystems. Out of the pesticides , fungicides contribute the most while insecticides contribute the least.	data availability and relied on self-reporting from golf course operators.
A Seven-Year Turfgrass Management Study Conducted	Bethpage State Park Farmingdale, NJ	The grass of all 18 holes at the Green Course was tested	18 holes from the Green Course at Bethpag	Grass was tested with different types of pest	Conventional Pest Management (CPM) maintained the best	The study was only tested on one course and didn't consider

at Bethpage State Park in New York (Grant et al., 2000)			e State Park	management at the Bethpage State Park golf course. The results were recorded based off of visual quality, performance, and risk to laborers	visual turf quality but had the highest environmental impact due to pesticide use. Integrated Pest Management (IPM) maintained acceptable turf quality and had reduced pesticide risk by up to 95 percent with only a small labor increase over time. Best Biological Pest Management (BBPM) did not consistently produce acceptable visual turf quality but	other climates, grass species, and management practices.
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					considerably reduced pesticide risk. The functionality of all surfaces remained the same.	
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Fig. 2 Summary findings of recent papers on environmental risks from pesticides used on golf courses

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