Extension
Turfgrass Science

Evaluation of Core Cultivation Practices to Reduce Ecological Risk of Pesticides in Runoff from Turf

Runoff studies were carried out to identify which core cultivation practice, solid tine or hollow tine, maximized pesticide retention at the site of application. Measured quantities of pesticides in the edge-of-turf runoff and characteristics of a local golf course were used to calculate pesticide concentrations in a surface water receiving turf runoff. Surface water concentrations of pesticides were compared to published toxicity data. Identifying management practices that reduce pesticide loss with runoff will improve disease and pest control in turf while minimizing undesirable environmental effects associated with the off-site transport of pesticides.

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Summary

Pesticides associated with the turfgrass industry have been detected in storm runoff and surface waters of urban watersheds; raising concern of their potential environmental effects and a desire to reduce their transport to non-target locations. Runoff studies were conducted to compare the effectiveness of solid tine versus hollow tine core cultivation to reduce the quantity of pesticides transported with runoff from creeping bentgrass (*Agrostis palustris*) turf managed as a golf course fairway. The concentration of pesticides anticipated in a surface water receiving the runoff were calculated using data from this study and runoff volumes and pond dimensions recorded from a local golf course. Surface water concentrations were compared with levels known to be harmful to aquatic organisms. Key observations of the study were:

- Runoff volumes were less from turf managed with hollow tine compared to solid tine core cultivation.
- Greater quantities of pesticides were transported off-site with runoff from turf managed with solid tines.
- Concentrations of pesticides in a pond receiving runoff from turf managed with solid tines exceeded levels harmful to eight of nineteen aquatic organisms evaluated.
- Replacing solid tine with hollow tine core cultivation reduced surface water pesticide concentrations to levels below harmful concentrations for most of these organisms.

Figure 1. Creeping bentgrass turf managed with solid tine (A) or hollow tine (B) core cultivation. Cores removed with the hollow tines were air dried and worked back into the turf prior to pesticide application and simulated precipitation.

Text

Pesticides are applied to highly managed biotic systems such as golf courses, commercial landscapes and agricultural crops. Golf course turf often requires multiple applications of pesticides at rates that exceed those typically found in agricultural or home environments (1,2). Pesticides associated with the turfgrass industry have been detected in surface waters of urban watersheds; leading to increased suspect of contaminant contributions from residential, urban, and recreational sources (3-7).

Fairways comprise approximately one-third of a typcial golf course (8), which may border surface waters such as ponds, streams, and lakes. Golf course fairways and greens may be managed with core cultivation during the spring or fall to control thatch, alleviate surface compaction, enhance water infiltration, and stimulate root and shoot growth (9-14). Cultivation with hollow tines typically involves removing cores from the turf, which are air-dried and brushed back into the open holes. Solid tine core cultivation requires a reduced amount of labor and is less disruptive to the surface of the turf but is believed to cause localized compaction (15).

Management practices have been shown to reduce runoff and pesticides transported with runoff from agricultural crops (16-18). Research on turfgrass has also shown the influence of cultural and irrigation practices on nutrient and pesticide transport with runoff and leachate (19-26). The goal of the present study was to identify which core cultivation practice, solid tine or hollow tine, maximizes pesticide retention at the site of application; thus improving desired results of disease and pest control in turf while minimizing undesirable environmental effects associated with the off-site transport of pesticides.

Runoff Study Site

Experiments were conducted on turf plots managed as a golf course fairway at the University of Minnesota, Saint Paul, MN, USA. The site (Waukegan silt loam) was divided into 6 plots (24.4 m x 6.1 m, length x width) and sodded with L-93 creeping bentgrass (*Agrostis palustris* Huds.) sod 14 months prior to initiation of the reported studies. The turf was managed as a fairway with 1.25 cm height of cut (three times weekly, clippings removed), topdressed with sand (weekly, 1.6 mm depth) and maintained with sprinkler irrigation.

Figure 2. A commercially available insecticide, fungicide, and herbicide were tank mixed and applied at label rates to all plots perpendicular to runoff flow; 63 d and 2 d following core cultivation and 26 ± 13 h prior to initiation of simulated precipitation and runoff.

Runoff collection systems were constructed at the western end of each plot, modified from the design of Cole et al. (21). Water traveled from the runoff gutter to a stainless steel flume equipped with an automated sampler and flow meter. Gutter covers and flume shields prevented dilution of runoff with precipitation. Plots were hydrologically isolated with removable berms.

Management Practices

Plots were aerated twice (June 21st, Sept 28th) with either solid tines (ST: 0.95 cm diameter x 11.43 cm length with 5 cm x 5 cm spacing) or hollow tines (HT: 0.95 cm internal diameter x 11.43 cm length with 5 cm x 5 cm spacing) and top dressed weekly with sand (Figure 1). Cores removed with the hollow tines were allowed to dry, broken into smaller pieces, and worked back into the turf. A back-pack blower and leaf rake removed the turf and thatch from the plot surface. Sand top dressing was not performed immediately after core cultivation or within a week of simulated precipitation and generation of runoff.

Pesticide Application and Simulated Precipitation

A rainfall simulator was constructed to deliver precipitation similar to natural rain (27) (Figure 2). Measured rainfall rates were similar to storm intensities recorded in Minnesota, USA, during July through October. Prior to initiation of simulated precipitation (48 h), each plot was pre-wet with the maintenance irrigation beyond soil saturation to allow for collection of background samples and to ensure uniform water distribution. Irrigation water samples and resulting background runoff were collected for analysis. Petri dishes were distributed across the plots to verify pesticide application rates and rain gauges were distributed throughout each plot to quantify simulated precipitation. A commercially available insecticide, fungicide, and herbicide containing chlorpyrifos, flutolanil, mecoprop-p, dicamba and 2,4-D were tank mixed and applied at label rates to all plots perpendicular to runoff flow (Figure 3). Simulated precipitation was initiated 26 ± 13 h after pesticide application. Soil moistures were 46 ± 7% water holding capacity within 3 h prior to initiation of the simulated precipitation.

Runoff Collection and Pesticide Analysis

Runoff water samples were collected using automated samplers equipped with a flow meter to recorded water level in the flume, calculated flow rates, reported total runoff volume and collected time-paced samples from each plot. Water samples were removed from the automated samplers and stored frozen until laboratory analysis. Concentrations of chlorpyrifos, dicamba, flutolanil, MCPP and 2,4-D were measured by direct injection of filtered samples onto a high performance liquid chromatograph with a photodiode array detector and quantified by direct comparison with external standard calibration curves of the analytical standards.

Calculating Pesticide Concentrations in a Pond Receiving Turf Runoff

Pesticide loads (mg m^{-2}) in the edge-of-plot runoff were calculated from recorded runoff volumes (L m^{-2}) and measured concentrations (mg L^{-1}) of pesticides in the runoff. Pesticide concentrations in a body of water receiving the runoff was determined using characteristics of a golf course located less than 20 miles from our study site; including the volume (L) of a pond receiving runoff from a known area of the golf course (m^{2}); considering the percentage

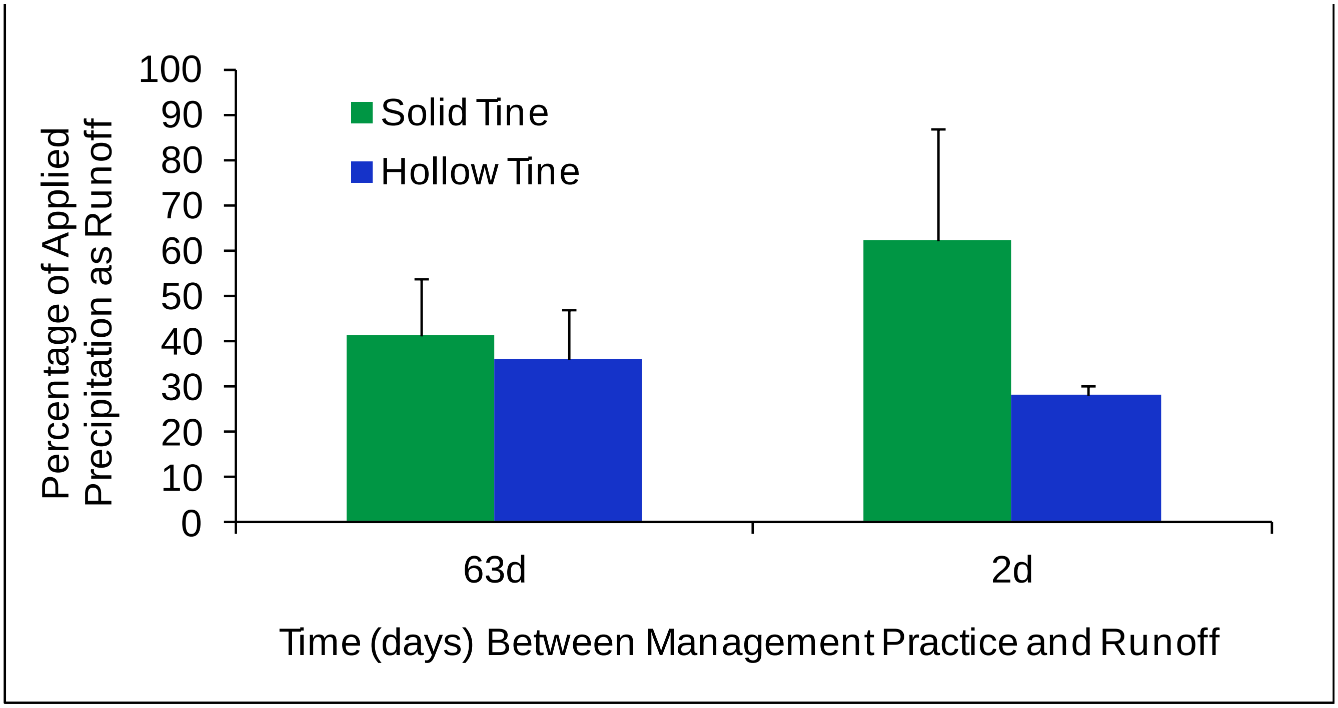
Figure 3. A rainfall simulator deliver precipitation resembling storm intensities recorded in Minnesota, USA. Runoff collection gutters guided runoff from the turf to flumes equipped with automated samplers and flow meters. Gutter covers and flume shields prevented dilution of runoff with precipitation.

of that area represented by fairway turf. Estimated pesticide concentrations in a pond receiving runoff from fairway turf managed with solid tine or hollow tine core cultivation were compared to published toxicity data to evaluate which core cultivation practice would be the most efficient at reducing environmental impacts. A detailed description of the calculations, toxicity data and statistical analysis are provided elsewhere (28).

Reduced Runoff Volume with Hollow Tine Core Cultivation

Runoff volumes were reduced in fairway turf plots aerated with hollow tine compared to solid tine core cultivation. Although the period of time between core cultivation and simulated precipitation was greater for the first runoff event (63 d) than the second runoff event (2 d), due to a delay in the construction of the rainfall simulator, the overall trends observed between solid tine and hollow tine core cultivation remained the same; showing reduced runoff volumes with hollow tines for more than 80% of the samples (63 d = 81%, 2 d = 87%). Calculation of cumulative runoff volumes from plots receiving core cultivation 63d prior to rainfall simulation demonstrated a 10% reduction in cumulative runoff volume with hollow tine (HT) relative to solid tine (ST) (HT = 3,149 ± 932 L; ST = 3,490 ± 1,107 L). A 55% reduction in cumulative runoff volume with hollow tine compared to solid tine core cultivation was observed when plot received core cultivation 2d prior to rainfall simulation (HT = 1,856 ± 139 L; ST = 4,164 ± 1,698 L). The percentage of precipitation resulting as runoff from plots aerated with hollow tines was less than quantities observed from the solid tine plots; suggesting greater infiltration with hollow tine core cultivation (Figure 4). Other researchers have measured enhanced water infiltration in turf managed with hollow tine core cultivation compare to untreated turf (29, 30) and greater saturated water conductivity and air porosity in turf managed with hollow tines compared to solid tines (15). The greatest difference in soil physical properties between plots was most prominent shortly after cultivation and diminishes with time as roots grow, compaction dissipates and holes are covered or filled; resulting in the greater distinction in runoff volumes between treatments at 2 d following cultivation compared to 63 d.

Figure 4. Mean percentage of applied precipitation measured as runoff from turf plots managed with solid tine core cultivation or hollow tine core cultivation 63 d and 2 d prior to simulated precipitation and runoff. Error bars represent the standard deviation of the mean.



Reduced Pesticide Transport in Runoff with Hollow Tine Core Cultivation

The quantity of pesticides transported with runoff from solid tine plots exceeded that of the hollow tine plots. Plots receiving hollow tine core cultivation to manage thatch 63 d prior to runoff showed a 17, 15, 24 and 23% reduction in cumulative dicamba, flutolanil, MCPP and 2,4-D loads, respectively. Cumulative loads of chlorpyrifos were similar. Following the second core cultivation (2 d), hollow tine plots displayed an even greater reduction in cumulative pesticide loads relative to the solid tine plots with 46, 55, 37, 35 and 57% decline in cumulative loads of dicamba, flultolanil, MCPP, 2,4-D and chlorpyrifos (Figure 5). Correlation analysis of pesticide loads with runoff volumes and pesticide concentrations revealed pesticide loads were attributed to runoff volume more than chemical concentrations for both management practices (volume $r = 0.78$ to 0.90, concentration $r = 0.05$ to 0.22). This greater correlation of pesticide load with runoff volume explains in part the increased pesticide transport associated with the solid tine plots compared to hollow tine plots and the increased difference in pesticide loads between cultivation practices at 2 d compared to 63 d.

Hollow tine core cultivation removed the cores and returned the soil back to the turf while solid tine core cultivation pushed the soil aside to create the channels. As a result one would anticipate greater soil compaction with the solid tine cultivation and increased accessibility of soil adsorptive sites with the hollow tine cultivation. This would influence hydraulic conductivity and infiltration as previously reported (15, 29, 30) as well as pesticide availability for transport (25, 31, 32). The percentage of applied pesticides observed in the runoff is also influenced by the physical and chemical properties of the active ingredient. Chemical degradation was not influential in the present study as the time from chemical application to runoff (30 ± 8 h) was much less than the reported half lives of the compounds of interest (5 to 320 d).

Reduced Risk of Pesticides in Receiving Surface Waters with Hollow Tine Core Cultivation

Calculated concentrations of pesticides in a pond receiving runoff from fairway turf managed with hollow tines or solid tines were compared with published toxicological endpoints for 19 aquatic organisms including fish, amphibians, mollusks, crustaceans, aquatic plants and algae (28). Toxicological endpoints included the median lethal concentration (LC50) and

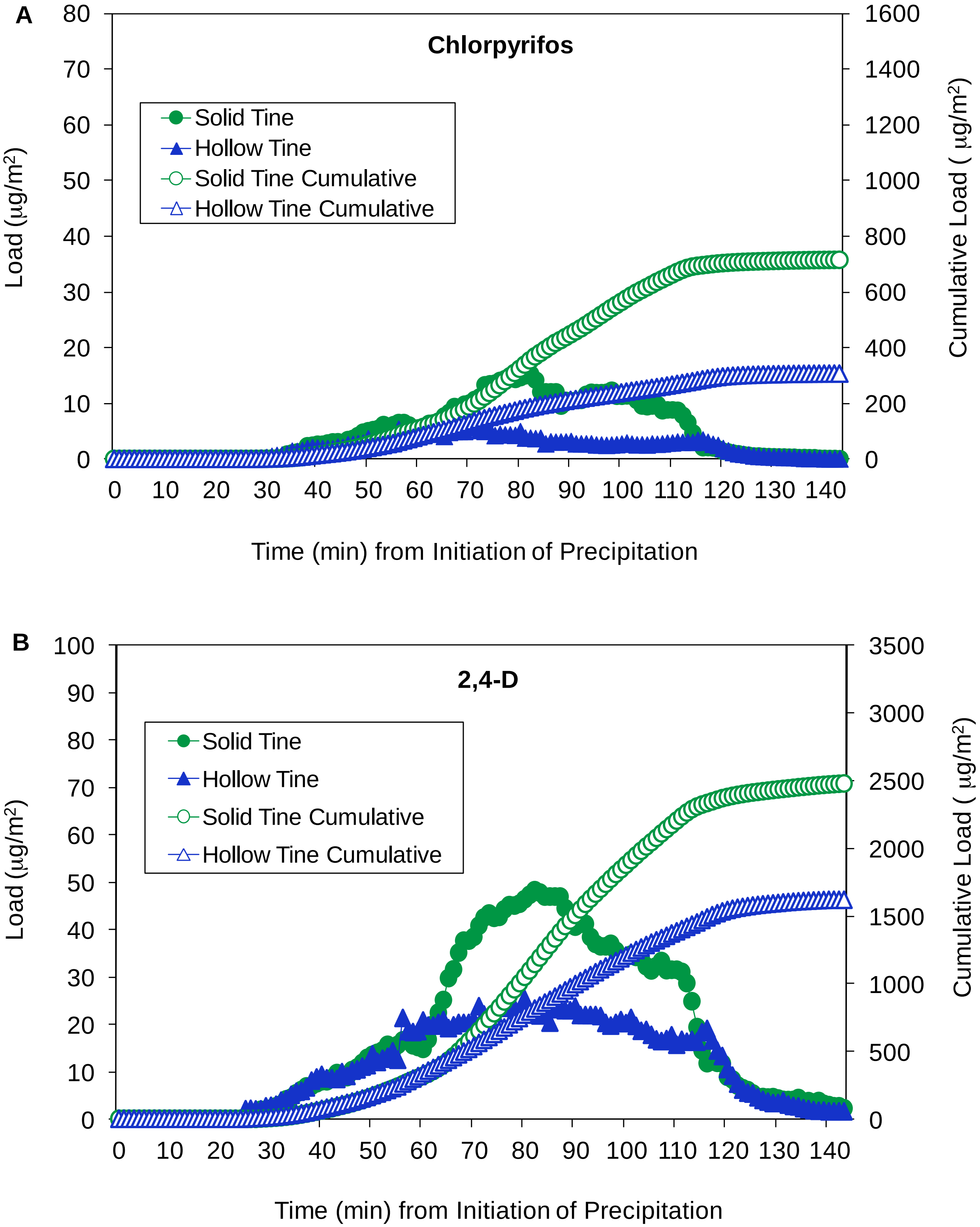


Figure 5. Chemographs and cumulative loads of chlorpyrifos (A) and 2,4-dichlorophenoxyacetic acid (2,4-D) (B) and measured in runoff from turf plots managed with solid tines or hollow tines 2 d prior to simulated precipitation and runoff. Data for dicamba, flutolanil, and mecoprop-p (MCPP) at 2 d and all pesticides at 63 d are provided elsewhere (28).

median effective concentration (EC50); or the concentration of a compound that results in the measured effect in 50% of the organisms during a defined exposure period. Pesticide levels in a surface water receiving runoff from turf managed with solid tines exceeded the LC50s or EC50s for eight of the 19 evaluated aquatic organisms. With a few exceptions at 63 d, replacing solid tine core cultivation with hollow tine core cultivation reduced surface water concentrations of chlorpyrifos to levels below the LC50 or EC50 for three fish (Figure 6A), MCPP to levels below the EC50 of a diatom (not shown), and 2,4-D to levels below the EC50 of an aquatic plant (Figure 6B). The sensitivity of rainbow trout, opossum shrimp and water fleas to chlorpyrifos and water fleas to 2,4-D was great enough that surface water levels exceeded the LC50s or EC50s regardless of the turf cultivation practice (ST, HT) (Figure 6A&B). Likewise, changes in management practice did not significantly influence the risk of pesticides to non-sensitive organisms (e.g. organisms who's LC50 is well above the maximum concentration estimated in the diluted surface water) (data not shown). Results of the present research provide quantitative information that will allow for informed decisions on cultural practices that can maximize pesticide retention at the site of application; improving pest control in turf while minimizing environmental contamination and adverse effects associated with the off-site tranpsort of pesticides. Using cultural practices that enhance infiltration and reduce runoff volume will effectively reduce pesticide runoff as demonstrated through the use of HT aerification.

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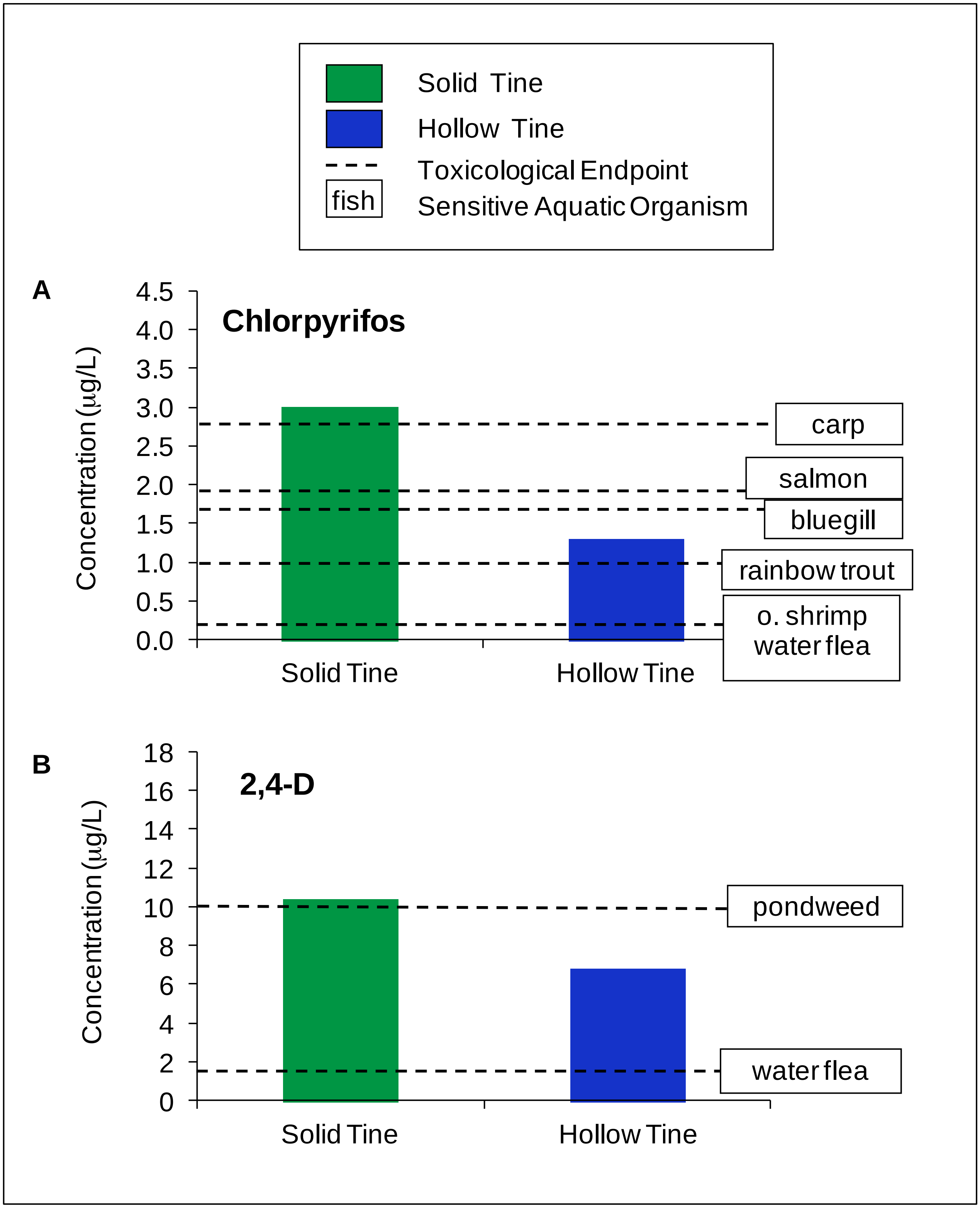

Figure 6. Comparing concentrations of chlorpyrifos (A) and 2,4-dichlorophenoxyacetic acid (2,4-D) (B) in a surface water receiving runoff from fairway turf managed with solid tines or hollow tines 2-d prior to runoff with toxicological end points (median lethal concentrations or median effective concentrations) of sensitive aquatic organisms. Toxicity data available at http://cfpub.epa.gov/ecotox/ecotox_home.cfm.

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