



Soil microorganisms: Your underground assistants

In established turfgrass systems, pesticides can bind to organic matter and degrade in the soil instead of being lost through runoff and leaching that contaminates groundwater and surface water.



Remarkable advances in the sensitivity of modern analytical techniques make it possible to detect pesticides at levels that would not have been discovered using earlier assay methods for quantifying contaminants in groundwater and surface water. In fact, many pesticides now can be detected in parts per quadrillion (ppq), which is approximately one drop of pesticide dissolved in 15 million gallons of water. These advances have led to detection of many pesticides in soil, surface water and groundwater (2,9,13).

As more highly managed turfgrass areas have become prominent components of the urban landscape (3,8), public concern about intensive use of fertilizers, pesticides and irrigation in these areas has increased. Unfortunately, close proximity to urban areas presents a unique problem for highly managed turf because pesticides and fertilizers could be applied inadvertently to concrete and/or asphalt areas, which do not impede movement of chemicals into surface water (ponds, lakes, streams, canals, etc.). Applying pesticides or fertilizers to these areas could, therefore, lead to eventual contamination of drinking water.

Although turfgrass management may provide the potential for environmental contamination, turfgrass itself may actually promote pesticide degradation. Frequent irrigation has been suspected of contributing to pesticide leaching and surface runoff, but the relatively high water content and nutrient-rich environment of most turfgrass soil systems may accelerate pesticide degra-

ation. Pesticide availability and degradation rate generally increase as temperature and soil-water content increase. Much information concerning pesticide dissipation, leaching and runoff is currently based on data from row-crop agriculture and therefore may be inappropriate for turfgrass systems. To gain a better understanding of this, turfgrass researchers at North Carolina State University have compared pesticide degradation characteristics in turfgrass soil systems containing differing amounts of organic matter.

Fate of chemicals on turfgrass

Can pesticides and fertilizers applied to golf courses lead to pollution of the environment? The answer depends on many factors, but proper training of applicators and common sense greatly reduce the potential for pollution. Luckily, superintendents have some control of the many natural processes that influence chemical behavior, including:

- solubilization by water
- sorption to soil particles
- microbial degradation
- chemical degradation
- photodegradation
- volatilization
- plant uptake and metabolism

The relative importance of each process is controlled by the chemistry of the pesticide and by environmental variables such as temperature, water content and soil type. One might expect pes-

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4 years



21 years



99 years

pesticide disappearance to be more rapid in turfgrass than in row-crop agriculture systems because soil microbial activity is greater in turfgrass (10,11). However, soil microorganisms first must be able to access the pesticide in order to break it down. Previous research has shown that access to pesticides can be greatly influenced by pesticide sorption to soil organic matter (7,12) (Figure 1).

Turfgrass systems differ from row-crop agriculture because, under favorable growing conditions, the grass canopy grows continuously, uninterrupted by harvest and crop removal. Leaf clippings are usually left on the turfgrass and allowed to decompose. Therefore, turfgrass systems represent a highly managed ecosystem in which soil organic matter accumulates (1,8). Taking into account the differences in organic matter and microbial activity, one would assume that pesticide fate in turfgrasses would be unlike that in row-crop agriculture.

Why do soil microbes help?

Soil microorganisms are the key component in the degradation of pesticides into nontoxic forms. Some soil bacteria, fungi and other microorganisms break down pesticides into carbon dioxide, water and some inorganic products and therefore are able to use the pesticides as food sources. However, most microbial degradation of pesticides occurs indirectly when microorganisms inadvertently consume pesticides along with other food sources in the soil. Research involving row-crop agriculture has shown that seasonal crop growth may influence soil microbial dynamics by altering the temporal and spatial distribution of organic inputs from root deposition and crop residues (4,6). Some turfgrass systems undergo a similar growth pattern involving a dormancy period and a period of active growth, depending on the turfgrass species and regional climatic conditions. Thus, timing of application may influence the

fate and degradation of the pesticide.

Soil microbial biomass, activity and pesticide sorption could be affected by a number of factors associated with the age of a turfgrass system. In newly created turfgrass systems, soil microbes are exposed to significant soil disturbance and associated adjustments in soil physical and chemical properties as a result of construction and establishment. As turfgrass systems age, soil microbes will be progressively challenged by changing environments associated with long-term management practices.

Previous and current research has determined that organic matter levels in surface soil tend to

Soil profiles (0-6 inches [0-15 centimeters]) taken from turfgrass systems at 4, 21 and 99 years after establishment. Photos by A. Hixson

Pesticide degradation & sorption

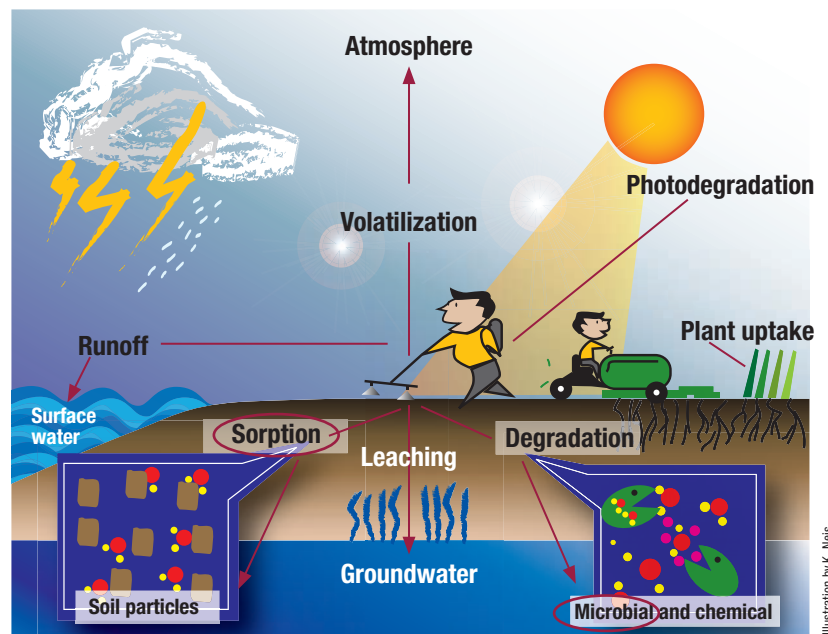


Figure 1. Turfgrass ecosystems differ from row-crop agriculture because soil microbial activity is greater in turfgrass. The grass canopy grows continuously, and clippings are usually left on the turf to decompose.

Illustration by K. Neis



Simazine was extracted (shaken) from soil for four hours using methanol.

increase as the turfgrass system ages. Higher levels of organic matter can support larger and more diverse populations of soil microbes, which may break down some pesticides more quickly (5,11). Furthermore, older turfgrass systems have been exposed to repeated applications of many pesticides, which may have caused soil microorganisms to become acclimated to them. These changes in soil biological characteristics could affect the environmental fate of pesticides applied to turfgrass systems of varying ages.

Experimental objectives

Our experimental objectives were first to confirm the hypothesis that soil organic matter levels increase as time since turfgrass establishment increases, and then examine the differences in fate of the herbicide simazine applied to surface soil and subsoil of these different-aged bermudagrass systems.

Soil properties

Soil	Soil C:N	Organic matter (%)	pH	Sand (%)	Silt (%)	Clay (%)
0–2-inch (0–5-centimeter) depth						
Native pines	19.0	3.5	4.6	92	6	2
4-year-old turf	14.3	1.5	6.3	96	2	2
21-year-old turf	11.4	4.1	6.0	96	2	2
99-year-old turf	11.1	4.5	5.4	92	6	2
2–6-inch (5–15-centimeter) depth						
Native pines	21.1	2.6	4.7	94	4	2
4-year-old turf	13.1	0.4	6.2	96	2	2
21-year-old turf	14.5	1.3	6.3	94	4	2
99-year-old turf	12.5	1.7	5.8	94	4	2

C:N, ratio of carbon to nitrogen.

Table 1. Properties of surface soils (0–2 inches [0–5 centimeters]) and subsoils (2–6 inches [5–15 centimeters]) from turfgrass systems of increasing ages.

Experimental approach

Soil sampling and preparation

Research involving degradation of simazine, a common herbicide, has been conducted in bermudagrass fairways of varying age near Wilmington, N.C. Fairways established in 1905, 1983 and 2000 were 99, 21 and 4 years old, respectively, when soil samples were taken. All soils were similar in texture with an average of 95% sand, 2% silt and 3% clay (Table 1). All sites are currently planted to hybrid bermudagrass (*Cynodon dactylon* × *transvaalensis*), a warm-season perennial. The oldest site had been replanted to different bermudagrass varieties numerous times, but constant turfgrass cover had been maintained from the time of establishment on all courses.

Intact soil cores (2 inches [5 centimeters] in diameter × 6 inches [15 centimeters] deep) were removed from three different fairways from each golf course in September and October 2004 before fall applications of simazine. Soils from adjacent pine forests were used for comparison to the highly managed golf course fairways and to assess the variability between sites independent of the golf course development. All cores were sectioned into 0–2-inch (0–5-centimeter) and 2–6-inch (5–15-centimeter) depths. Soil from each depth was sieved (<0.16 inch [4 millimeters]), combined and stored at 39 F (4 C) for later analysis after visible roots and plant residues were removed.

Degradation experiment

Degradation characteristics of simazine in surface soil (0–2 inches [0–5 centimeters] deep) and subsoil (2–6 inches [5–15 centimeters] deep) of bermudagrass fairways were determined using laboratory techniques. A simazine solution radio-labeled with carbon-14 was prepared with commercial-grade simazine to be applied to the soil. Radio-labeled herbicides allow researchers to easily track the movement and dissipation of herbicides in plants and soil systems.

Sterile and nonsterile soil microcosms consisting of eight 0.7-fluid-ounce (20-milliliter) glass scintillation vials filled with 0.53 ounce (15 grams) of soil each within a 34-fluid-ounce (1-liter) glass jar were used as sample units. For comparison, half of the soil microcosms contained sterilized soil to measure simazine degradation in the absence of soil microorganisms. A 0.7-fluid-ounce (20-milliliter) scintillation vial containing 0.35 fluid ounce (10 milliliters) of sodium hydroxide solution was placed in each jar to trap the carbon dioxide produced (carbon dioxide is a measurement of soil microbial activity). Glass jars were capped and placed in a constant temperature

room in the dark at (77 F [25 C]) to simulate soil conditions (Figure 2).

Fifteen-gram soil samples were analyzed at zero, one, two, three, six, nine, 12 and 16 weeks after treatment. During this incubation time, jars were aerated weekly, and the sodium-hydroxide traps were changed twice weekly for the first four weeks, and once a week thereafter. At each sampling time, sodium-hydroxide traps were removed and sealed for later analysis.

Subsequently, 1.7 fluid ounces (50 milliliters) of methanol were added to each soil sample, shaken vigorously and filtered through glass-fiber filter paper with suction. These extracts were evaporated to dryness and redissolved in 0.35 fluid ounce (10 milliliters) of methanol. To quantify the extractable fraction of simazine at each time period, 0.03 fluid ounce (1 milliliter) of this extract was analyzed by radio assay.

To measure the amount of soil-bound simazine, two 0.04-ounce (1-gram) air-dried methanol-extracted soil samples were oxidized in a biological oxidizer at 1,634 F (890 C). To quantify the extent of simazine mineralization by soil microorganisms, 0.03 fluid ounce (1 milliliter) of the sodium-hydroxide trapping solution was assayed to determine the amount of radio-labeled carbon dioxide produced. Sterility was monitored throughout the experiment by radio assay and titration of sodium-hydroxide traps to detect any radio-labeled carbon dioxide or total carbon dioxide produced.

Results and discussion

Simazine added to sterile soil that had no microbial activity showed substantial potential for binding to organic matter. Simazine's binding capacity was directly related to organic matter content. After 16 weeks of incubation, 52% of applied simazine was bound in surface soil (0-2 inches [0-5 centimeters]) from the 4-year-old turfgrass system with 1.5% organic matter; 70% was bound from the 21-year-old turfgrass system with 4.1% organic matter; and 71% was bound from the 99-year-old turfgrass system with 4.5% organic matter (Figure 3). Conversely, when nonsterile soil with high microbial activity was examined, significant microbial degradation occurred. As the simazine in the soil was degraded, radio-labeled carbon dioxide was produced: 77% was released from the surface soil of the 4-year-old turf, 87% from the surface soil of the 21-year-old turf and 69% from the surface soil of the 99-year-old turf (Figure 4). Soil-bound simazine in surface soil accounted for 18% (4-year-old turf), 11% (21-year-old turf) and 22% (99-year-old turf) of applied simazine after



16 weeks of incubation (Figure 5). Higher levels of soil-bound simazine and lower microbial degradation in the older turfgrass system indicate soil microorganisms are unable to access the simazine easily (Figures 3, 5). Because less soil organic matter is found in younger turfgrass soil systems, less simazine binds to the soil, and more microbial degradation occurs.

As turfgrass systems age, simazine binds readily to increasing levels of organic matter and is less available to microorganisms for breakdown. Simazine microbial degradation estimated by radio-

Radio-labeled carbon dioxide captured in 10-milliliter vials of sodium-hydroxide trapping solution.

Microcosm design

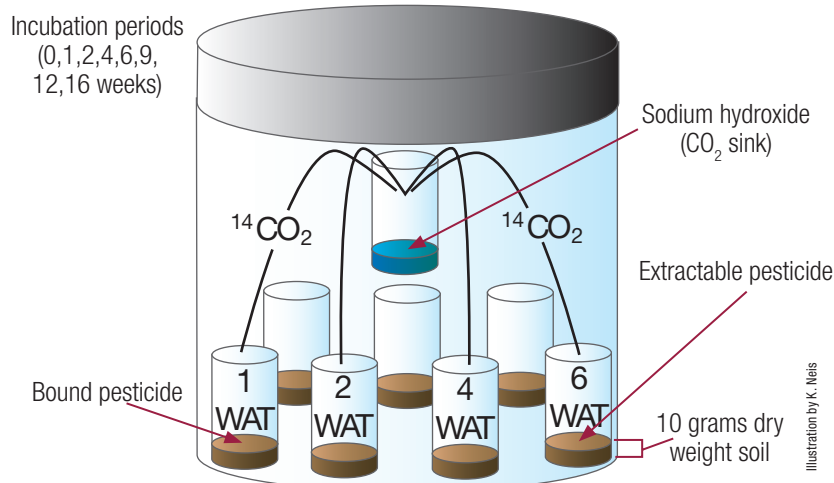


Figure 2. Each of the 16 treatment combinations was placed in a separate microcosm (34-fluid-ounce [1-liter] jars) and replicated three times for a total of 48 microcosms. Each microcosm held seven vials with 0.53 ounce (15 grams) (dry-weight) soil per vial and one vial with sodium-hydroxide to trap carbon dioxide. On each sampling day, one vial was removed and analyzed. Sodium-hydroxide traps were removed weekly and analyzed. Each lid was sealed with Teflon, and 0.35 ounce (10 milliliters) of distilled water was placed in the bottom of each vessel to maintain a humid environment. WAT, weeks after treatment.

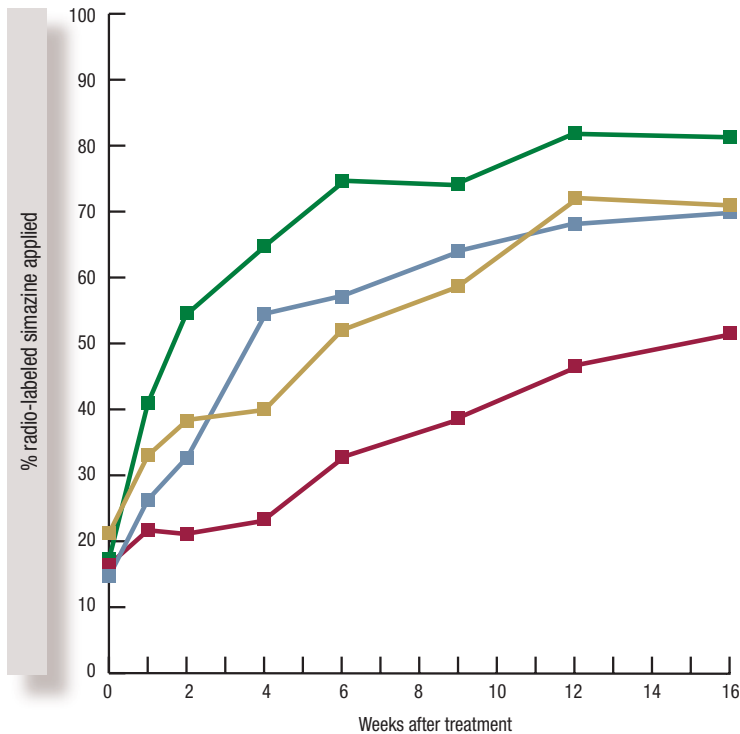
Illustration by K. Neis



Bound — surface soil

Sterile soil

99-year-old turf 21-year-old turf 4-year-old turf Pine forest



Extractable — surface soil

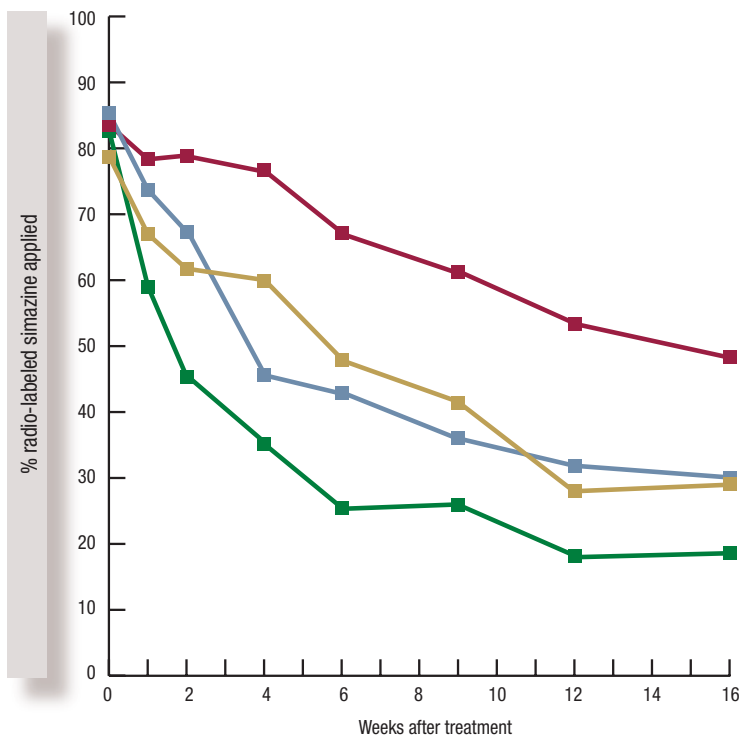


Figure 3. Bound and extractable radio-labeled simazine from sterile surface soil [0-2 inches (0-5 centimeters)].

labeled carbon-dioxide production was similar at both depths in the older turfgrass system, indicating the accumulation of organic matter over time is crucial to the fate of pesticides in managed turfgrass systems (Figure 4). Radio-labeled carbon-dioxide produced from pine forest soils was very low throughout the experiment, indicating very little microbial degradation (Figure 4).

In the 4- and 21-year-old turfgrass systems, soil depth seems to have a large impact on the microbial degradation of simazine. In both systems, the extractable simazine fraction remained above 50% and radio-labeled carbon dioxide accounted for less than 26% of applied simazine six weeks after treatment at the 2-6-inch (5-15-centimeter) depth (Figure 3, 5). In these younger turfgrass systems, if simazine is able to move below the 2-inch (5-centimeter) depth in the soil profile, degradation may be delayed.

Results from sterilized soil show that older turfgrass systems had less extractable simazine, and the lowest levels were found in soils from pine forests (Figure 3). In general, as turfgrass systems become older and organic carbon levels rise, more simazine binds to soil particles and is therefore less bioavailable. These results show that the interaction between soil organic matter and simazine is an important determinant of simazine leaching potential. As turfgrass systems age and organic matter levels increase, the potential for simazine to leach into groundwater decreases even though biological degradation rates may be lower.

Conclusions

Turfgrass is sometimes called the world's best filtration system because turfgrass systems provide a highly sorptive layer of organic matter with high microbial activity that reduces the potential for problems caused by the introduction of pesticides into the environment. Bioavailability of the pesticide simazine to both plants and soil microorganisms depends on the level of organic matter in soil systems, which is why microbial degradation, as measured by radio-labeled carbon-dioxide production, is lower in the surface soil of the oldest bermudagrass system in this study. Higher bioavailability equates to more microbial degradation and plant uptake and a small but greater opportunity for leaching into groundwater. Although our research only involves simazine and bermudagrass, we can use the findings to substantiate previous claims that turfgrasses reduce pesticide runoff and potential for groundwater contamination.

Research involving pesticide and nutrient fate in turfgrass often shows that turfgrass systems reduce surface runoff; increase sorption on



leaves, thatch and soil organic matter; maintain high microbial and chemical degradation rates, and reduce leaching during active plant growth because turfgrass has greater plant uptake and higher transpiration rates. Although superintendents should remain vigilant in protecting the environment, numerous research studies have shown that turfgrass is very effective in preventing pesticides and nutrients from reaching groundwater and surface water.

Superintendents must make it a priority to educate their green committees, golfers, surrounding homeowners and the general public about how turfgrass is consistent with environmental stewardship. In addition, they must lead by example and employ cultural practices that reflect a genuine concern for the health of the environment. These practices will not only help protect our environmental resources, but also validate the importance of the profession.

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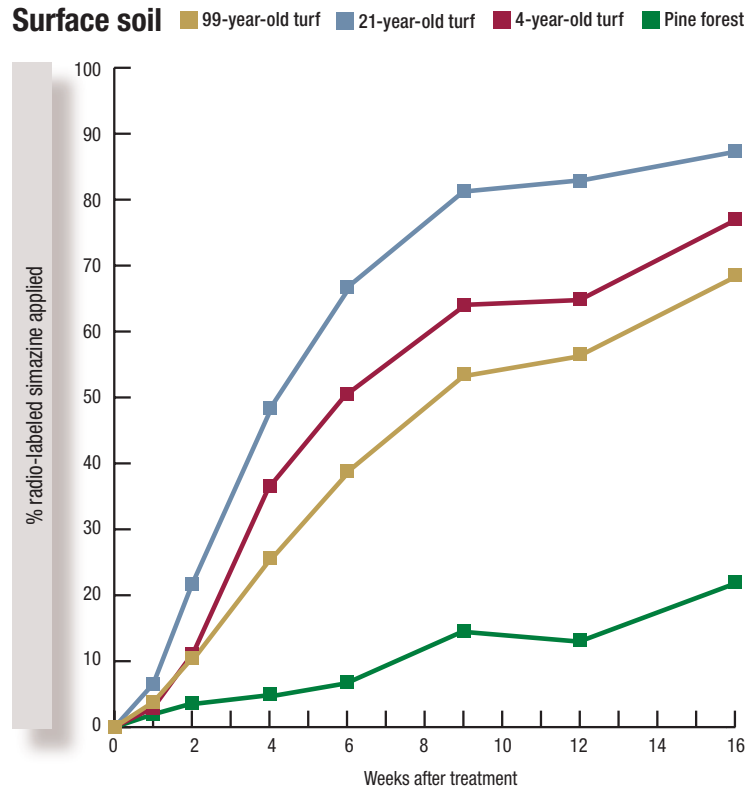
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Cumulative carbon dioxide



Subsoil

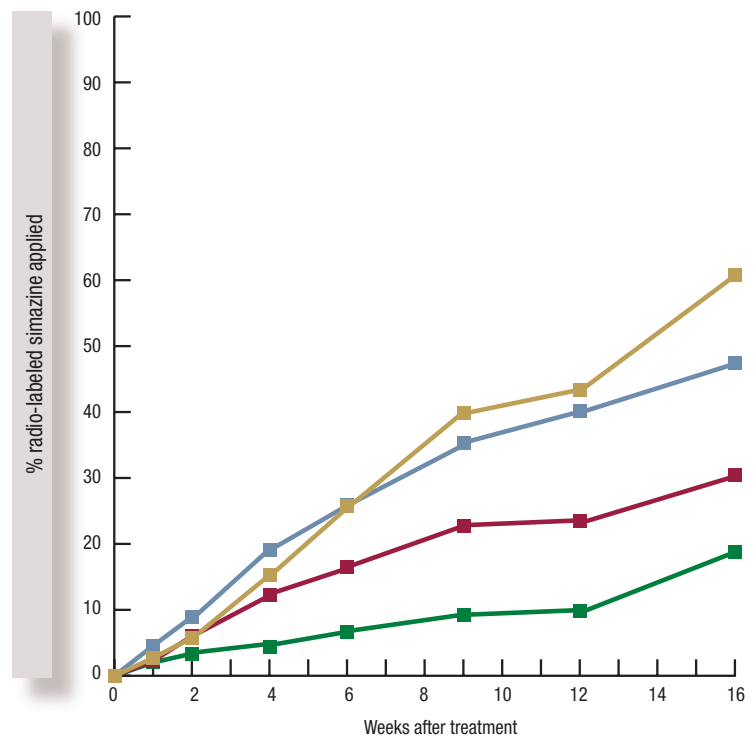


Figure 4. Radio-labeled carbon dioxide produced from nonsterile, microbially active soil at two depths: surface soil, 0-2 inches (0-5 centimeters); and subsurface soil, 2-6 inches (5-15 centimeters).



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GCM

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Nonsterile soil

99-year-old turf 21-year-old turf
4-year-old turf Pine forest

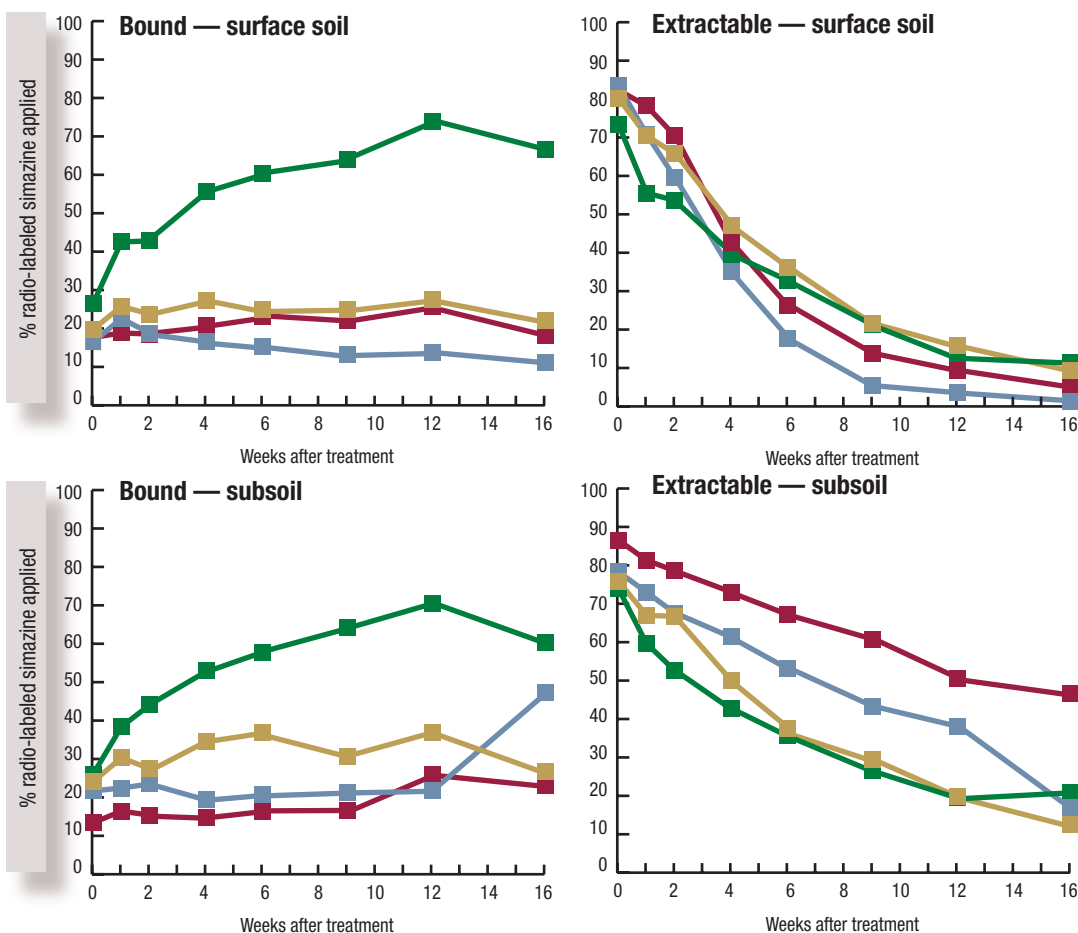


Figure 5. Bound and extractable radio-labeled simazine from nonsterile microbially active soil at two depths: surface soil, 0-2 inches (0-5 centimeters); and subsurface soil, 2-6 inches (5-15 centimeters).



The research says

- As more highly managed turfgrass areas have become prominent components of the urban landscape, public concern about intensive use of fertilizers, pesticides and irrigation in these areas has increased.
- Our study, which involved bermudagrass turf systems and the herbicide simazine, showed that organic matter levels increase as turfgrass systems age.
- As organic carbon levels rise, more simazine binds to soil particles and is therefore less bioavailable so that simazine leaching potential is decreased.
- Although our research only involves simazine and bermudagrass, we can use the findings to substantiate previous claims that turfgrasses reduce pesticide runoff and potential for groundwater contamination.