BU-5726-F
Reviewed 1997

MINNESOTA EXTENSION SERVICE
UNIVERSITY OF MINNESOTA
COLLEGE OF AGRICULTURAL, FOOD, AND ENVIRONMENTAL SCIENCES

A joint publication of the University of Minnesota Extension Service and Iowa State University Extension

Originally a joint publication of the Minnesota Extension Service, University of Minnesota, and Iowa State University Extension.
Prepared by Robert J. Mugaas, Hennepin County Extension horticulturist, University of Minnesota; Michael L. Agnew, Extension horticulturist-turf; and Nick E. Christians, professor of horticulture, Iowa State University.

The Benefits of Turfgrass

Trees and shrubs provide the green vertical dimension in landscapes. Lawns provide the green carpet on which these plantings lie. A well-maintained lawn creates an inviting view for passersby and supplies the perfect backdrop for other landscape elements. The grassy areas confer coherence on the landscape by pulling the design together.[44]

The growing point of grass is at or near the ground line, permitting regular cutting at a 2 to 3 inch height, and giving turf its ability to thicken and recuperate from the foliar damage caused by modest mowing. Thus, a well-maintained lawn can always be uniform in appearance, contributing a sense of harmony to the scene.[44]

Healthy grass is often viewed as an aesthetic asset rather than a cash crop. But a growing body of evidence points to the positive health and environmental contributions made by lawns and other turfed areas.[6,29] A healthy, vigorous lawn with good plant density provides the following benefits:[6,29,44,57]

- produces, with every 25 square feet, enough oxygen for one person for one day;
- provides significant cooling;
- reduces noise by absorbing, deflecting, reflecting, and refracting sounds;
- traps and thereby helps control dust and pollen in the air that can cause allergic reactions;
- reduces discomforting glare and light reflection;
- absorbs gaseous pollutants (such as carbon dioxide) from vehicles, thus serving to combat the greenhouse effect implicated in global warming.

Turfgrasses can play a significant role in reducing runoff and pesticide and nutrient leaching.[44,57] Water volumes running off natural groundcover areas may be as little as 10 percent of rainfall, compared to 55 percent from mostly paved areas.[10] As urbanization progresses, more hard, water-impervious surfaces are constructed—streets, driveways, parking lots, and roofs. The result is not only increased surface runoff but a decrease in the time elapsed before runoff occurs.[10,44]

But a healthy, vigorous turf can take up lots of water. In fact, a thick and carefully managed turfgrass allows 15 times less runoff than does a lower quality lawn.[29] A healthy, dense stand of turfgrass can reduce runoff volume to almost zero.[57,60] An average golf course of 150 acres can absorb 12 million gallons of water during a 3-inch rainfall.[29] Research has shown the infiltration rate on dense, sodded slopes is about 7.6 inches per hour. On slopes with less cover, the water penetrates at about 2.4 inches per hour.[44]

The increased surface runoff associated with increasing urbanization has also raised concerns about lawn fertilizers and pesticides getting into the water.[56] However, well-maintained lawn areas can play a key role in significantly decreasing surface runoff losses. In fact, runoff loss from a healthy stand of grass is a lot less than that from traditional row crop agriculture. For example, grassland experiences 84 to 668 times less erosion than areas planted to wheat or corn.[29] When comparing runoff losses of nitrates and phosphates from tobacco and turfgrass, the values were about 84 to 120 times greater respectively, from the tobacco crop than from the turfgrass.[21] Pasture runoff is often much higher than lawn runoff because pastures are more compacted and not as densely vegetated as lawns.[1,44]

Thick healthy lawns are found to limit pesticide runoff. Dense turf reduces the velocity of runoff by allowing greater infiltration into the thatch and grass rootzone where microbes can begin the work of breaking down the materials.[44,58]

The turfgrass rootzone is itself a unique soil system. A healthy turf rootzone will help[4]: **1)** improve soil structure and reduce soil compaction thus allowing greater infiltration of rain or irrigation, **2)** improve soil processes that facilitate the biodegradation (breakdown) of various types of organic pollutants, air contaminants, and pesticides used in lawn care, **3)** encourage soil building processes through decomposition of organic matter and formation of humus, and **4)** contribute to easier lawn care with less weed, insect, and disease incidence.

Minimizing the Use of Fertilizers and Pesticides

The first objective of any lawn care program should be to provide an optimum environment for healthy grass plants. A healthy and vigorous lawn is the best defense against attack or invasion by various pests. A healthy lawn is likely to recuperate readily from modest insect or disease attacks without the use of pesticides.

Creating a healthy lawn is similar to any other type of gardening. But instead of tending a few large plants, such as flowers or vegetables in a small garden area, you are tending millions of small individual grass plants growing over relatively large areas (about 800 per square foot).[44] Still the same kinds of good gardening practices used in vegetable and flower gardens apply to growing grass plants. Although the means to achieve optimum conditions for lawns are somewhat different than for gardens, such conditions are just as necessary for producing healthy grass plants as they are for growing fine tomatoes.

However, reaching for more fertilizer and more pesticides is not always the best means of achieving optimum grass growing conditions. In fact, limiting additions of these inputs to a lawn can reduce or even eliminate potential water contamination problems. Before using additional fertilizers and pesticides, first consider some important lawn care practices other than fertilizers and pesticides to a healthy lawn.

Improving the soil

When installing a lawn, consider adding some organic matter—such as peat moss or compost—to either a sandy soil or a heavier clay soil. (Apply 5 to 20 percent by volume; 1 inch of organic matter to 5 inches of soil equals 20 percent by volume.) This improves water and nutrient retention in a sandy soil, and improves drainage and aeration characteristics in a heavier clay soil.

Larger quantities can be used with lighter sandy soils; smaller quantities should be used with heavier clay soils. Thoroughly mixing the organic matter into the soil will improve and enlarge the rootzone area for the grass plants.[6,12] An extensive root system occupying larger soil volumes provides the grass plant greater capability to withstand adverse environmental conditions and plant stresses.

Although it is tempting to add sand to a heavier clay soil to improve its drainage and aeration characteristics, don't do it. Adding only small amounts of sand (such as an inch or two) usually makes the condition worse. To use sand effectively for modifying a heavy clay soil, you'd need to add quantities of 80 to 90 percent by soil volume—about 8 to 9 inches of sand for every inch of clay soil. At these high rates, the sand particles can start to contact or bridge with each other, thereby opening up larger soil pore spaces.[12] In most situations, adding this amount of sand is not practical. Adding organic matter usually is a better alternative.

Another way to improve the rootzone of your existing lawn is by alleviating soil compaction. This can be done with a core cultivator, which removes small plugs of soil from the ground and deposits them on the lawn surface. These are available from many local rental agencies. Several passes in different directions across the lawn area puts holes into the ground and begins the process of rootzone improvement. Leave the small soil cores on the surface; they'll decompose naturally in a few weeks. Severely compacted soils may need two to three treatments per year for the first few years. The degree of play and traffic a lawn receives determines future frequency of core cultivation. Cultivation improves the water infiltration characteristics of soil, thereby reducing runoff from compacted sites.

Watering

Proper watering plays a major role in the lawn's ability to tolerate stress and resist pest problems. While approximately 1 to 1-1/2 inches of water per week (including rainfall) are necessary to keep the lawn green during the growing season, the amount applied at any one time should be governed by the type of soil. For example, since sandy soils do not hold water well, water applied beyond the needs of the grass and the moisture-holding capacity of the soil simply moves down beyond the rootzone. This represents poor use of water that may carry plant nutrients beyond the rootzone—especially nitrate, a form of nitrogen. Once nitrate moves beyond the rootzone where plants can extract and use it, the potential for water contamination increases. Splitting water applications into two or three 1/2-inch applications per week may be better suited to sandy soils.

Clay and clay loam soils have slower infiltration rates, hold water much better than sands, and may be too wet at times for good grass growth to occur. But larger amounts of water can be added per application, providing it's not applied so fast that most of it runs off. Matching the infiltration rate of the soil to the delivery rate of the sprinkler is the goal of effective and efficient watering. With these soils, one 1-inch or two 1/2 inch applications of water per week is usually sufficient.

Overwatering can also cause problems. Soils that are continuously wet, particularly in the spring and fall, can predispose grass plants to some fungal disease problems, especially those associated with the root system. Grass blades that are wet for long periods encourage the development of some fungal diseases. Hence, watering early in the day is generally a better practice than watering too late in the evening. Overwatering creates a succulent turf plant that transpires water readily. Appropriately watered grass is better conditioned to survive slight drought stress conditions.[12]

Where cool-season grasses are allowed to go into a state of summer dormancy, they should be properly conditioned to withstand the dry and often hot conditions. As the summer stress period approaches, gradually reduce the water supplied to your lawn. This conditions the turfgrass plant to drier conditions and increases survival. Don't stop watering abruptly! Even with properly conditioned turf, applying 1/4 to 1/2 inch of water every two to three weeks on a heavier soil will prevent dehydration of the grass plant crowns to a point beyond recovery. On sandy soils or during prolonged periods of high temperatures, shorter intervals may be needed to achieve the same result. Once cooler temperatures and natural rainfall return in late summer or early fall, regular irrigation practices can be resumed if needed.

Where grass root systems are very shallow due to compacted soils and/or heavy thatch levels, provide regular irrigation throughout the growing season. Under these conditions, severe drought stress can result in significant turf losses.

Schedule irrigation to replenish the water lost to evaporation and used by the plant. This provides a healthier turf, and will minimize the potential problems associated with concerns about leaching and runoff.[1]

Mowing

Regular mowing with a sharp mower blade set at the proper height keeps the grass growing vigorously and at adequate density to thoroughly cover the soil surface. Continually scalping the turf will seriously weaken the grass plants, thereby creating opportunities for pest and weed invasions. For most lawn areas, mowing at a height of 2 to 3 inches provides a good quality turf. This slightly higher height screens out light to the soil surface and provides some level of weed control. This limits the establishment of weeds such as crabgrass, whose seeds need light to germinate. A slightly higher height of cut also encourages a slightly deeper root system that allows roots to gather moisture and nutrients from a larger soil volume, giving grass a greater degree of stress tolerance. But where grass has become very tall, it is better to lower the height of cut gradually, rather than cut it back all at once.

Whenever possible, return grass clippings to the lawn. They provide a valuable source of nutrients—especially nitrogen—for future use by the grass plants.[50] In fact, doing this may reduce yearly nitrogen applications by 1/3 to 1/2.[51] Mulching mowers and mulching attachments for existing mowers can reduce the clipping size, increasing the rate at which grass clippings decompose. But mowing on a regular basis with a sharp mower blade produces clippings that decompose fairly quickly without further size reduction.

Historically, clippings were collected because it was thought that they contributed to thatch buildup. Although grass clippings contain some stem tissue, they are primarily composed of leaf blades, which have a significantly lower lignin content than stem tissue.[2] This leaf blade tissue is rapidly decomposed by soil microorganisms.[2,33] Therefore, grass clippings do not contribute significantly to any long-term thatch buildup.[33]

Recommended mowing heights for Upper Midwest grasses are listed in **Table 1** (page 4). Grass clippings can be left on the lawn when the lawn is mowed regularly at these heights. Increasing the mowing height by 1/2 inch during the summer can improve the lawn's ability to tolerate stress.[2]

Thatch management

Thatch is a tightly intertwined layer of dead and living grass stems and roots that develops between the soil surface and the area of green vegetation. This layer develops when the accumulation rate of dead organic matter from the actively growing turfgrass exceeds the rate at which it is decomposed.[6]

While some thatch (less than 1/2 inch) gives resiliency to turf and is considered beneficial, excessive amounts can cause problems, acting as a home and harbor for several turf insect pests and some turf diseases. The major cultural factors that contribute to thatch accumulation include: vigorous growing grass varieties, acidic conditions (especially within the thatch layer), poor soil aeration, excessively high nitrogen levels, and infrequent and high cutting heights.[6] Managing thatch to minimal levels through vertical mowing, core cultivation, or topdressing keeps pest problems to a minimum, reducing the need for pesticides. A healthy soil environment allows grass plants to use fertilizer nutrients more efficiently and allow organic materials, such as grass clippings, to decompose faster.

Quality as affected by shade

Cool-season turfgrasses do not perform well under shady conditions, such as a wooded homesite or forest. This can lead to a number of turfgrass problems. In these environments it is best to plant fine-leaved fescues—creeping red fescue (*Festuca rubra* L.), chewings fescue (*Festuca rubra* L.ssp. *commutata*), hard fescue (*Festuca longifolia* Thuill.), and rough bluegrass (*Poa trivialis* L.). All these grasses have some shade tolerance, but under dense tree canopies there may not be sufficient light to sustain their growth either.

Diseases, combined with the lack of light intensity, can severely thin shaded lawns. It is tempting to provide additional fertilizer and water to compensate for the root competition from the shrubs and trees, but this usually makes things worse, causing further stand density reduction. Generally, there is less need for fertilizers and pesticides in shaded areas. Increasing sunlight through appropriate pruning—or even removal of some trees and shrubs—is usually the best way to improve the turf stand, if that is the goal. Where trees and shrubs are considered a higher priority, the best alternative would be to choose other types of groundcovers or mulches. Trying to grow grass in a heavily shaded area is usually not a good use of landscaping resources. Eventually the turf thins out increasing the potential for soil erosion and increased runoff, especially on slopes.

Inputs as a last resort

Even when proper cultural practices are used, there are times when some pest control or fertilizer supplements are necessary. For example, though all the clippings may be returned to the lawn, they may not be providing enough nitrogen for the quality and density required of that turf area. Since turfs of greater density provide better protection against runoff and leaching problems, this may be a situation where additional fertilizer may be needed to improve overall turf density.

Occasionally, insect populations reach serious damage levels even in the best of lawns. If that is the case, applying a proper chemical or biological control may be a better choice than risking the loss of large turf areas. Turf loss to insects can result in a multitude of other problems such as weed invasion or runoff problems.

Lawns that have been poorly maintained may require herbicides to eliminate weeds and fertilizers to speed recovery, after which appropriate cultural practices can be resumed.

Table 1

Mowing Heights

Kentucky bluegrass	
Common or public varieties (e.g., South Dakota Common, Park, S-21, Argyle, Kenblue)	2 - 3 inches
Improved varieties (included in most sod blends; most varieties not mentioned above)	3/4 - 2-1/2 inches
Fine fescue grasses	1-1/2 - 3 inches
Perennial ryegrass	1 - 2-1/2 inches
Bluegrass/fine fescue mix	2 - 3 inches
Bluegrass/perennial ryegrass mix	1 - 2-1/2 inches

Using Fertilizers Responsibly

Few soils have enough natural fertility to maintain desired turfgrass quality and recuperative ability throughout the growing season.[6] When natural soil processes do not provide adequate supplies of the essential nutrients, fertilizer should be added to maintain optimum (not necessarily maximum) turfgrass growth.[51] Nitrogen (N), phosphoros (P), and potassium (K) are three key elements needed for plant growth and are usually applied as supplemental fertilizers. To maintain turf density and quality, they are required in larger quantities than is generally available from soil.

The primary objective in applying fertilizer to a lawn is to add necessary nutrients **in the required amounts** and **at the proper time** to achieve desirable turf quality and plant health. A healthy turf can recuperate more quickly from insect and disease attacks than a stressed lawn and be more competitive with weeds, thereby reducing the need for pesticides.

Soil testing

One of the first steps in responsible fertilizer management is to have the soil tested. Soil tests provide information about the soil texture, whether it is acid or alkaline (its pH value), and the levels of organic matter content, P, and K. However, soil tests for N are usually performed by special request only. That is because N is highly mobile in the soil and the tests generally provide little useful information relative to lawns.

But P and K are more stable in the soil, so test results more accurately reflect amounts available for the plants. Once you've obtained background information, the task of developing a responsible fertilizer program becomes a lot easier. Soil testing services are provided by state university extension services and private laboratories. If needed, local county Extension offices can provide help in interpreting test results.

NITROGEN MANAGEMENT

Ample supplies of N promote vigorous growth and green color in turf. However, too much or too little N can cause problems. Shortages can lead to slow growth, yellowing of the plants, increased susceptibility to some diseases, and a thin turf. Conversely, an overabundance can lead to excessive shoot and leaf growth, reduced root growth, low carbohydrate (food) reserves in the plant, increased susceptibility to environmental stresses, and some diseases.[6,51]

Fertilizer N sources are often categorized as either inorganic or organic types. A brief description of several N sources is given in **Table 2**, page 6.

Inorganic products include ammonium nitrate, ammonium sulfate, calcium nitrate, and potassium nitrate. These materials are all water-soluble, quick-release N sources—meaning N becomes available as soon as water is applied to turf. Response to these sources of N is quite predictable, and results are fairly immediate. But their burn potential is high and their effect is rather short lived. On sandy soils, high application rates of these products, combined with high irrigation or rainfall amounts, may result in substantial N losses due to leaching.

Nitrogen can be purchased in either liquid or granular form; there is essentially no difference in the type of plant response.[34,51] Ammonium nitrate, for example, can be applied as a liquid or a granular material. Either form is a quick-release form of N, and the grass will respond accordingly.

Organic fertilizer products—natural or synthetic—contain carbon (C) in their chemical structure, along with other elements. Natural organic sources include fertilizers derived from some type of natural organic material such as processed sewage sludge, composted animal and plant debris, or other processed organic wastes like cottonseed meal and seaweed extracts. These materials release N slowly; that is, N becomes available only after the product is broken down by chemical and/or microbial processes in the soil. Natural organic products are primarily broken down through microbial action. Through this process, plant available N is gradually released to the soil solution. Microbial activity and the consequent N release are is governed primarily by temperature and moisture. Soil conditions that are too hot, dry, cold, or wet may adversely affect the performance of these products. Compared to quick-release N sources, these sources have a lower leaf burn potential and can be applied at somewhat higher rates without damage to the turf.

Urea is the most common synthetic organic N. It is considered a quick-release, water-soluble N product and can be applied as either a liquid or a granular material. However, it does have a relatively high leaf burn potential and a high potential for volatilization. For that reason, urea is often further processed and/or combined with other materials to produce fertilizers with more of a slow-release N characteristic. Examples of such products include ureaformaldehyde, isobutylidene diurea (IBDU), and sulfur or resin-coated urea. A number of these sources are listed in **Table 2.** These fertilizer materials behave like the natural organic products—that is, N release is dependent on chemical and/or microbial action. These products have a lower leaf burn potential and can be applied at somewhat higher rates without injury to the turf than quick-release sources. Some urea-formaldehyde products have been put into solutions and suspensions and can be applied in liquid form. Sulfur- and resin-coated urea products are applied as dry granular materials. Natural-organic sources are most commonly available as granular products, but can be purchased as a liquid (seaweed extract). When comparing liquid or dry granular fertilizer options, be sure to consider the type of N source—slow-release or quick-release—rather than whether it is a dry or liquid formulation.

Environmental Fate of Nitrogen

Since the late 1980s, the fate of N applied to turf has become an environmental issue. After application, a number of things can happen to N.[39,55,56]

- volatilization back to the atmosphere as N gas,
- bind with soil organic matter where it may later become available for plant growth,
- can be taken up by the plant and used for the various growth processes,
- be carried by water past the turf rootzone potentially contaminating groundwater,
- run off and affect surface water resources.

The last two possibilities can be minimized by knowing some key characteristics of the fertilizer product and how to properly apply it, and being familiar with the site to which it's applied.

Surface runoff

Whenever N is applied to a site, there is the possibility that some of it may run off into surface waters. However, several recent studies indicate that N carried in runoff from turfed areas is very low,[21,35,39,60,61] and is usually much less than the EPA established drinking water standard of 10 ppm nitrate-N.[35,39,60] That's because turf is comprised of many closely spaced plants forming a relatively closed canopy over the soil surface. Turf density, leaf texture, and turf canopy height are the primary factors relating to the resistance of surface movement of water over turf. Nearly 80 percent of the extensive fibrous root system of turfgrass is located in the upper 2 inches of the soil.[61] Both the protective nature of the canopy and the root system are responsible for the stabilizing effects of turf.[44,61]

Table 2

Characteristics of Common Turfgrass N Sources

Fertilizer Source	N Content %	Leaching Potential	Burn Potential	Low Temp. Response	Residual Effect
Inorganic					
Ammonium nitrate	33-34	High	High	Rapid	Short
Calcium nitrate	16	High	High	Rapid	Short
Ammonium sulfate	21	High	High	Rapid	Short
Organic Ñ Natural					
Activated sewage sludge	6	Very Low	Very Low	Very Low	Long
Manures	3-10	Very Low	Very Low	Very Low	Long
Other natural products	3-10	Very Low	Very Low	Very Low	Long
Synthetic					
Urea	45-46	Moderate	High	Rapid	Short
Urea solutions	12-14	Moderate	High	Rapid	Short
Sulfur coated urea	14-38	Low	Low	Moderate	Moderate
Resin coated urea	24-35	Low	Low	Moderate	Long
Isobutylidene diurea (IBDU)	0-31	Mod. Low	Low	Moderate	Moderate
Methylene ureas and Ureaformaldehyde*	38	Low	Low	Low	Mod. Long to Long

*some products may contain urea in addition to the ureaformaldehyde component.

Leaching

A second concern about N is that the nitrate (NO_3) form may leach into groundwater supplies which, in turn, may discharge into surface water. Unlike P, nitrate-N is not bound to soil particles and, consequently, can move rather freely through the soil with water. Once beyond the turfgrass rootzone, nitrates can continue moving through the soil and may find their way into water sources.

The degree to which nitrate leaching is a potential problem is related to soil type, irrigation practices, type of N source, rates of N application, and season of application.[39] Leaching problems are greatest in the following situations: **1)** on coarse-textured soils such as sands and sandy loams; **2)** when quick-release N sources are applied at high rates followed by heavy irrigation or rainfall; and **3)** when a quick-release source of N is applied during times when the grass is not actively growing.[20,39,56] However, by being aware of these possibilities, knowing your site, and adapting proper management practices, you can play an important role in minimizing nitrate-N leaching.

NITROGEN MANAGEMENT PRACTICES

Understanding the characteristics of the fertilizer product you're using and a familiarity with your site may help minimize—or even eliminate—adverse impacts on water quality. Follow the manufacturer's guidelines for more specific product information while relating that to your own unique situation.

To protect water quality while using nitrogen fertilizers, keep the following information in mind:

1. On sandy sites, N source, rate and timing of application, and irrigation practices influence groundwater contamination potential.

2. The amount of nutrients required by your lawn or turfgrass area depends on the type of grass plants and the management practices you use—that is, how much care you decide to give your lawn, balanced with the demands of the grass variety. Divide lawns into high- and low-maintenance groups, based on management practices. High-maintenance lawns are characterized by vigorously growing plants, such as the improved Kentucky bluegrass varieties and the turf-type perennial rye grasses. These lawns perform better when provided with adequate water and fertilizer during the growing season. Low-maintenance lawns usually consist of the common types of bluegrasses combined with a mixture of other grasses. **Table 3** describes the annual application of N requirements for these various lawn types, and addresses how leaving clippings on the lawn affects yearly N needs.[51] Note: P and K requirements should be determined by a soil test.

3. On highly leachable soils (sands and sandy loams), the recommended application rates shown in **Table 3** may apply too much water-soluble N at one time, resulting in excessive loss of nitrate-N due to leaching. This could be especially true if the N source is quick-release, followed by heavy irrigation or rainfall. Several studies have suggested that applying lower rates of a soluble N source more frequently may minimize leaching problems.[1,4,8,18,31,32,38,39,42]

4. For sandy soils, slow-release types of N are probably a better choice. This is especially true for lawns in close proximity to surface- or ground-water resources. The potential nitrate-N leaching is less from slow-release than from quick-release N sources. This is true of both natural and synthetic slow-release sources (see **Table 2,** page 6).

5. Where soluble N sources are used on sandy soils, reducing the application rates (0.25 to 0.5 lb. N/1,000 ft^2 per application) will minimize the possibility of leaching N beyond the rootzone.[1,31,32,38] Even on heavier soils, frequent applications at lower levels of a soluble N source may give a more even response to turfgrass growth.

6. Since slow-release N sources provide a more sustained N supply, application rates as high as 2 lb. N/1,000 ft^2 can be used on Kentucky bluegrass. Actual rates are based on the ratio of water-insoluble N (WIN, slow-release fraction) to water-soluble N (WSN, quick-release fraction). A large WIN/WSN ratio indicates a high percentage of slow-release N is contained in the product and a higher rate of application is possible. Always follow manufacturer's guidelines for proper use.

7. Nitrogen leaching is most likely to occur during cool rainy weather. Cool temperatures decrease denitrification and volatilization losses, along with decreased microbial activity and plant nutrient uptake. This means that nitrate-N is likely to be present beyond levels that can be used by the plants and microorganisms, leaving more to leach from the site and affect groundwater resources. This will be especially true on sandy sites.[1,39]

8. Watering practices that move water beyond the rootzone may increase potential N leaching. Since nitrate-N is soluble, it can easily move with water through the soil profile and enter water systems. Frequent, daily irrigation during cool periods of the year also can increase N leaching. So can infrequent deep irrigation. This happens by moving water (and the nutrients dissolved in it) well past the rootzone before the plants get a chance to use them. To be both appropriate and effective, irrigation practices should take into consideration the grass plants' needs during any particular climate condition. The key is to add only enough water to compensate for that removed by plant uptake and evaporation; this will minimize potential pollution problems from runoff and leaching.

9. Sloped areas may require more frequent applications of water (less water applied each time), because some of the water may run off before it gets the chance to soak in properly. The steeper the slope, the harder it is to maintain an adequate soil moisture level throughout the growing season. Core

Table 3

Annual Nitrogen Requirements and Application Timing for Lawns in the Upper Midwest[51]

Maintenance Practices	Nitrogen (N) to Apply *lb. N/1,000 ft^2	Timing of Applications
High maintenance lawn		
(Irrigation, clippings removed)	4	May, June, Aug., Sept., Oct., Nov.
(Irrigation, clippings not removed)	3	May, June, Aug., Oct., Nov.
Low maintenance lawn		
(No irrigation, clippings removed)	2	Aug., Oct., Nov.
(No irrigation, clippings not removed)	1	September

* Assume 1 lb. N/1,000 ft^2 of a soluble, quick-release N source applied at each application.

Note: Lower, more frequent rates of a quick-release N fertilizer can be used on sandy to sandy loam soil. Slow-release N fertilizers could also be substituted for the quick-release types. Follow manufacturers and/or Extension suggestions for proper application rates.

cultivation, especially on heavy soils and/or compacted areas, improves infiltration rates and can reduce this problem. South and west slopes encounter greater drought and heat stresses than east or north slopes. South and west slopes will likely require greater attention to water needs during the warm and dry parts of summer.

10. Irrigation of 1/4 to 1/2 inch immediately after application of a soluble N source provides the following benefits:

• moves the N into the soil, decreasing the possibility of it volatilizing into the atmosphere;

• moves the N off the surface, precluding possible runoff problems; and

• moves the N into the rootzone where it can be used by the grass plant.

11. Those who practice late season fertilization should take soil type into account to determine the most appropriate product and application rates. On sandy soils consider using frequent, low rates of a quick-release N source or substitute a slow-release N source.[1,4,7,24,39] Fertilize turf areas after the shoots have ceased their growth, but well in advance of the ground freezing. Turfgrass shoots stop growing about the time temperatures are consistently below 45^o to 50^o F. However, the leaves are still green and able to make food through photosynthesis. Nitrogen can be absorbed by the plant and stored for use next spring.[24] **Never apply fertilizer to frozen ground.**

12. Except for special situations (such as golf greens), return grass clippings to the lawn area to decompose. Since grass clippings are a source of nutrients (particularly N), they should not be blown into street gutters, sidewalks, or driveways where they can be carried by runoff to surface waters, nor should they be blown directly into surface water areas. If these nutrients get into the surface water, they can cause excessive growth of undesirable algae and other vegetations.

PHOSPHORUS MANAGEMENT

Phosphorus is an essential macronutrient contained in every living cell. It is involved in important grass plant functions including:

• using and transforming energy in the plant. This process involves the molecule adenosine triphosphate (ATP), which contains high energy for use in making (or breaking down) various organic compounds;[6,16,54]

• formation of a significant part of the plant's genetic material in the cell nucleus;

• carbohydrate transformations, such as converting starch to sugar.

Yet, in spite of its important role, the amount of P needed by the grass plant is significantly less than its demands for N and K. Phosphorus enhances turfgrass establishment, rooting, and increased root branching. It is particularly important during the early stages of seedling growth and development. In fact, P deficiency symptoms are most likely to occur during the period of turf establishment. Such symptoms include reduced growth and tillering, dark-green to reddish leaf color, narrow leaf blades (often with a tendency to curl), and a reduced capacity to retain moisture making plants look wilted.[6,16,54] While P is an important nutrient for grasses and other green plants, it is also a nutrient for algae and weeds in lakes. In comparison to the relatively rich natural supply of other important elements for plant growth (carbon, hydrogen, oxygen, nitrogen, and sulfur), P is least abundant, and most commonly limits biological productivity in fresh water environments.[15,47,62] Thus, lake enrichment with P can cause undesirable algae blooms and vigorous growth of other lake weeds, a process termed eutrophication. For this reason, concern about the contribution of lawn and garden fertilizers to lake pollution has been growing. But proper application techniques for each given turfgrass site should pose little or no threat to water resources.[45] More likely, it is misuse or misapplication of these materials that is causing the problems.

Phosphorus fate in soil

Many complex reactions involve P in soils. Phosphorus combined with oxygen is termed phosphate and is the form primarily absorbed by plants. The most common phosphates absorbed by plants from solution in the soil are the primary ($H_2PO_4^-$) and secondary (HPO_4^{-2}) orthophosphate ions. Small quantities of soluble organic phosphates may also be absorbed, but are considered of only minor importance.[41,53,54]

Phosphates are immobile in the soil. In fact, at any given time, little P is available for plant uptake from the soil solution. Therefore, the amount of P required by plants usually exceeds the small supply available in the soil. Thus, P must be replenished near an actively growing root. This replenishment is apparently due to an equilibrium between soluble (available) and insoluble (unavailable) forms of P near the root-absorbing zone. As the available pool of P near the roots is depleted by plant uptake, some of the insoluble P is solubilized and becomes available for plant uptake. Phosphorus from adjacent parts of the soil system (where the P concentration is higher) then move to the root area by diffusion. If the total supply of P in the soil is ample, enough P will reach the root system by this process so as root systems grow and expand into larger soil volumes, they contact previously untapped sources of soil P that can then be absorbed.

In many instances where grass clippings are not removed, the decomposition of the grass blades can supply enough soluble P so future P additions can be reduced or even eliminated.[41,53,54] Take a soil test to determine whether or not you need to provide additional P on any particular turfgrass site.

Off-site movement of phosphorus

Since phosphates are removed from the soil solution and immobilized in the soil, they are not very leachable from the soil and hence pose no threat to groundwater contamination.[45,56] Off-site transport of P to surface waters, however, tends to be associated with sediment erosion because P is carried along with the soil (silt and clay fractions primarily) and organic matter sediments.[15,45,47,56] As various forms of organic matter—including grass clippings, leaves, and natural fertilizer sources—are broken down, soluble forms of phosphates are produced. If these do not infiltrate into the soil where they can be immobilized, they represent a potential pollution source to surface waters from runoff.[45,47,52] This problem may be accentuated during periods when the ground is frozen and soluble phosphates are leached from dead plant tissue. As there is no chance for infiltration to occur, these soluble phosphates can then move directly into the runoff streams. Typically these periods include rainfall late in the year on frozen ground or during snow melt periods in winter and early spring.[3,52]

Runoff from established, relatively dense turfgrass areas is very low, even on slopes.[21,44,61] Although sodded sloped areas can immediately control runoff, seeded slopes allow more runoff, even three years after installation.[59,60] Establishing grass covers, such as along roadways, is considered a desirable landscape management practice for minimizing surface runoff.[10,17]

In a study of storm runoff into Minneapolis lakes, which compared areas where P-free fertilizer had been applied with those receiving P-containing fertilizers, little or no difference was observed in P in the runoff water.[46] Reducing organic plant residues carried in runoff water may help reduce the amount of P entering lakes.[15,46]

Phosphorus attaches to finer soil particles (clays, silts, and organic matter), which are most easily lifted from soil or other surfaces and carried off by wind.[30,45] If these particles are deposited into a lake, the attached P comes along with it. Although this form of pollution is difficult to control, living plants such as trees, shrubs, and, in particular, turf areas around lakes can reduce the problem considerably. Not only does this vegetation prevent wind and water pollution by stabilizing the soil, it also acts as a filter by removing these fine particles from the air.[44,45]

PHOSPHORUS MANAGEMENT PRACTICES

The fate of P in soil is somewhat less complex than that of nitrogen. Since P can be a significant contributor to lake eutrophication, proper management of P on turf is just as important as proper management of N. Following are some suggestions to consider when using P fertilizers to help protect surface water quality.

1. Phosphorus additions to turf areas should be based on a reliable soil test. These can be obtained from soil testing labs at land-grant universities or through private soil testing laboratories.

2. Phosphorus is immobile in the soil and does not pose a threat to water resources from leaching. However, when sediment is eroded from a site, some P will be carried with it. In turfgrass areas, runoff potential is quite low due to the physical characteristics of the turfgrass cover. Therefore, when P is applied to turfgrass areas, it should be watered in to preclude being carried in runoff.

3. Grass clippings, leaf litter, and other forms of organic debris should be removed from hard-surface areas where they could be carried in runoff to surface water areas. During the winter months, leaves, grass clippings, and other organic debris may, upon breakdown due to freezing and thawing, release soluble forms of phosphate and nitrates. These can be carried off from frozen ground in runoff into surface water areas during spring snow melt and early spring rains. Therefore, raking your lawn in the fall to remove excess organic debris may be beneficial.

4. Since P is essentially immobile in soil, it is often advisable to add some P in new turf establishments, even though soil P levels may be adequate for established turf. This will ensure some available P near the soil surface for young developing roots. Protecting newly seeded areas (especially slopes) with some type of mulch cover during establishment prevents runoff and erosion of soil and possible nutrients. Applying P after core cultivation will help get P into the soil of an existing turf cover.

GENERAL FERTILIZATION PRACTICES

Improper management and use of turf fertilizers can contribute to pollution of both surface waters and groundwaters. Being careful to avoid over-application or misapplication of these materials, and basing lawn nutrient requirements on a reliable soil test, are the first steps in responsibly using fertilizers to protect water resources. Combining appropriate landscape management practices with a modest turf fertilization program may further reduce potential water pollution. Following are some additional general fertilization practices that can reduce water pollution from fertilizers.

1. Never directly deposit or inadvertently apply fertilizers into lakes.

2. Fill fertilizer spreaders on a hard surface where spills can be cleaned up easily. **NEVER** wash fertilizer spills into the street or other hard-surface areas where fertilizer can enter storm sewers and ultimately surface water.

3. Close the gate on the fertilizer spreader when crossing hard-surface areas or go back and sweep up the material for reuse.

4. Drop spreaders are more precise but slower than rotary spreaders. Near shoreline areas, apply fertilizer near the lake with a drop spreader to create a buffer zone. Then you can fertilize the area away from the shoreline with a rotary spreader. Take the same precautions when using liquid applications.

5. Avoid getting fertilizer into natural drainage areas or pathways on a property. These may not necessarily be hard-surface areas. Fertilizer can be carried directly into surface water before it has a chance to infiltrate into the surrounding turf/soil area.

6. For shoreline areas, try to leave a buffer zone of unmanaged grasses, or possibly natural vegetation, around the shoreline. This natural area helps prevent erosion from adjacent shore land, and may retain some nutrients that would otherwise go into the lake.[45]

Using Pesticides Responsibly

Besides tolerating low level pest populations without suffering permanent damage, properly maintained and healthy turfgrass will also recover rapidly from pest or disease infestations.[56] As the demand for high quality lawns has increased, so has the dependence on pesticides for achieving near perfect lawns or playing surfaces. Meeting public demand for high quality turfgrass and a uniform playing surface on golf courses often requires intensive management practices, including use of pesticides. While it's true that chemical pesticides can help provide sustained turfgrass quality despite the cultural and economic benefits (often reducing both labor and energy costs[56]), controversy over the environmental effects of pesticide use has emerged. Consequently, many homeowners and turf managers must now make informed choices about the best approach for managing their lawns or turf areas to minimize adverse environmental impacts.[28]

Pesticide residues resulting from overuse or improper use have been associated with adverse environmental effects. Some of these are:[3,40]

• reduction of certain bird populations;

• appearance of detectable residues in aquatic ecosystems;

• implication of many pesticides as potential carcinogens;

• long-term soil contamination with persistent pesticides;

• destruction of nontarget organisms and evolution of resistant pest strains.

Pesticides may also be subject to leaching and/or runoff which can affect groundwater and surface water quality.[56]

FATE OF PESTICIDES IN THE ENVIRONMENT

Pesticide movement by surface runoff or leaching is influenced both by the properties of the pesticide and the soil/turfgrass environment.

PESTICIDE PROPERTIES

Important pesticide properties relating to their environmental fate include soil adsorption, water solubility, and persistence in the soil.[9]

Soil adsorption values indicate how strongly a pesticide binds to soil particle surfaces. The soil surfaces most active in binding pesticides are the organic matter and clay fractions.[9,11,56] Pesticides may also be adsorbed by the extensive fibrous turfgrass root systems.[14] Soil adsorption values are designated by the symbol Koc. Values greater than 1,000 indicate a pesticide that attaches strongly to soil and is unlikely to move unless soil erosion occurs. Products with values less than 300 to 500 tend to move with water; they have the potential to leach or move off-site with surface water runoff. Products with intermediate values may be of concern depending on the influence of other cultural or environmental factors.[9]

Water solubility indicates how easily a pesticide may be washed off plant residue and/or leach downward through the soil. Solubility is determined in water at room temperature and is expressed in terms of parts per million (ppm). This value is the same as milligrams per liter (mg/1). Pesticides with solubilities of 1 or less tend to remain at the soil surface and are not prone to leaching, although they may move off-site with soil sediment. Pesticides with solubility greater than 30 ppm are quite soluble in water and more likely to leach. Intermediate values may be of concern depending on other cultural or environmental factors.[9,56]

Pesticide persistence, or half-life, is expressed in days, and represents the time required for a pesticide in the soil to degrade to one-half its initial concentration. The longer the half-life, the greater the potential for pesticide movement through either leaching or runoff. For example, pesticides with a soil half-life greater than 21 days may persist long enough to leach or move with surface runoff before degrading. But it's important to keep in mind that half-life values should be used only as relative indicators of persistence. Soil moisture, temperature, soil oxygen status, microbial populations, soil pH, and other factors can play a significant role in how long a pesticide persists in the soil.[9]

While these guidelines can be used to select appropriate pesticides, it is the interaction of these properties that more accurately determines how a pesticide believes in a particular environment. For example, the herbicide trifluralin is a common preemergence herbicide for controlling warm-season, annual, weedy grasses. Based on its half-life of about 60 days, you might suspect that it would be subject to leaching. But because it is water insoluble and holds tightly to soil particles, it won't. However, if the site were subject to possible erosion due to a thin stand (normally, dense turfgrass covers prevent erosion), this pesticide could move off-site in runoff water.[9] In another example, glyphosate is water soluble, but is strongly adsorbed to soil particles which prevent its leaching.[56] These ratings may help make rough estimates of the relative leaching and surface runoff potential of pesticides.

ENVIRONMENTAL INFLUENCE

After application, a variety of things can happen to a pesticide that influence its effect on the environment. In general, pesticide fates fall into two categories: transportation processes and transformation processes. **Table 4** lists the more important transportation and transformation factors affecting fate of pesticides.

Transportation processes result in the movement of a pesticide away from its intended site of action. Of the four movement processes, leaching and runoff potential are of primary interest because they may affect water quality.

Transformation results when a pesticide's chemical structure is altered—usually a desirable fate, because most pesticides used today become less toxic or nontoxic.

TRANSPORTATION PROCESSES

Leaching

Leaching is the downward movement of pesticides and nutrients through the soil. Pesticides with a high leaching potential have a high water solubility (300 to 500 ppm) and low soil adsorption values.[14] But turfgrass density, depth and quantity of rooting, and thatch development have been shown to significantly affect leaching potential.[14]

Recent studies from several universities have demonstrated that grass and thatch present a barrier to movement of several common turfgrass insecticides and herbicides.

At Ohio State University, research with several turfgrass insecticides has shown that penetration into the soil below the grass is seldom deeper than 1 to 1-1/2 inches.[14] When isazophos (Triumph), isofenphos (Oftanol), ethoprop (Mocap), chlorpyrifos (Dursban), and bendiocarb (Turcam) were applied to a golf course fairway, 98 to 99 percent of the residue remained in the thatch layer 1 to 2 weeks after application. Residues in the 1 inch of soil below the thatch never exceeded 0.8 ppm during the 34-week sampling period.[36]

Similar Ohio research evaluating the vertical mobility of several preemergence turfgrass herbicides noted that most (77 to 100 percent) of the pendimehtalin, bensulide, and oxidiazon residues remained in the thatch layer. When applied to thatch-free turf, 82 to 99 percent of recovered residues from the same materials remained in the upper 1 inch of soil.[27] Other research has shown that pendimethalin is relatively immobile and not generally susceptible to leaching[14,48,49] when applied to turfed areas.

Leaching of 2,4-D and dicamba from Kentucky bluegrass lawns grown on sandy loam soil has also been examined.[19] During a two-year leachate study, low concentrations of both 2,4-D and dicamba were observed, suggesting that the turfgrass rootzone had excellent degradation conditions. Consequently, buildup of either herbicide in soil beneath a healthy lawn is unlikely.

Recent research on four golf courses on Cape Cod in Massachusetts provided evidence for the immobility of several turfgrass fungicides, insecticides, and herbicides.[13,23] Four courses were selected as likely to have groundwater contamination based on their hydrogeologic vulnerability (permeable, sandy soils), history of high pesticide and fertilizer use, and golf course age (greater than 30 years). The researchers said these courses should represent a worst case scenario for potential groundwater contamination. Key results from the study included no detection of the seven pesticides—mecoprop (MCPP), siduron (Tupersan), pentachlorophenol, anilazine (Dyrene), iprodione (Chipco 26019), diazinon, and dacthal. The highly mobile herbicides 2,4-D and dicamba were detected only once each in about 70 samples, both in amounts well below their health advisory limit values. Isofenphos (Oftanol) was detected once and chlorothalonil (Daconil) was detected twice. In all instances, detection values were below stated health advisory limit values. Finally, not one of the currently registered turfgrass pesticides was detected at toxicologically significant levels.[13] Preliminary results from a similar Florida study also showed no contamination of groundwater. However, this research is still being conducted, with further evaluation and a greater number of samples planned.[25]

Although the scientific data regarding the potential leaching of pesticides into groundwater below turfgrass areas is limited, what is available is encouraging.[13,14]

Table 4

Factors Affecting Pesticide Fate

Adapted from (11)

Transportation processes:
- Leaching
- Runoff
- Volatilization
- Adsorption
- Plant absorption

Transformation processes:
- Photodecomposition
- Microbial decomposition
- Chemical degradation

Runoff

Runoff occurs when the precipitation rate exceeds the soil's water infiltration rate. On row crop sites, where pesticides are applied to bare soil and not held in place by plants, loss of pesticides and nutrients can be significant. When runoff occurs from these areas, a pesticide can dissolve and be carried off-site in runoff water or, if bound tightly to soil particles, it can be carried as sediment in runoff water.[11]

But as recent studies have shown, well-maintained, densely turfed areas can reduce runoff to nearly zero.[11,14,58] These areas have the potential to absorb large quantities of precipitation. Estimates suggest that a 150-acre golf course has the capacity to absorb 12 million gallons of water during a heavy (3-inch) rainstorm. That's because the grass slows down the water enough to allow most of it to infiltrate before it can run off.[14]

Unlike row crops, soil erosion on established golf courses is virtually nonexistent.[58] Research at Pennsylvania State University has shown that even under extreme conditions, the amount of runoff from sodded slopes is small.[58] When runoff samples were analyzed for the herbicides 2,4-D, 2,4-DP, dicamba, and pendimethalin, none was detected in the majority of samples, and when detected, the concentrations were low. No chloropyrifos was detected in any of the samples.[59] In a later study, neither pendimethalin nor chlorpyrifos was detected from turfed slopes in runoff or leachate samples.[22,58]

Although runoff research from turfed areas is limited, the initial findings are encouraging. Turfed areas significantly limit runoff, thereby greatly reducing the chances for off-site movement of nutrients and pesticides.

Volatilization

Volatilization of a pesticide occurs when it changes from a solid or liquid phase to a gaseous phase. This change in physical state occurs at a specific pressure (known as the vapor pressure) for that pesticide. Vapor pressure is the point where solids vaporize and liquids evaporate.[11,58]

Volatilization is generally a concern when using broadleaf herbicides formulated as esters.[11] Esters tend to volatilize more readily than amines. Sometimes additions are made to the ester molecule to make a lower volatile ester that can be used more safely.

However, ester formulations should never be used under hot, dry conditions (when temperatures exceed 80¡-85¡ and the relative humidity is low).[58]

Absorption

Absorption is the movement of pesticides into plants and, to a much lesser degree, soil microorganisms. Once absorbed, most pesticides are broken down by the plant. When the plant or plant part dies, any remaining residues can serve as a food (energy) source for soil microorganisms.[58]

TRANSFORMATION PROCESSES

Photodecomposition

Sunlight-induced transformation can be an important fate for some pesticides. These changes generally alter a pesticide's chemical properties, making it less toxic (sometimes less effective) and more susceptible to further breakdown by chemical or microbial processes.[58]

The dinitroaniline herbicides (e.g., benefin, trifluralin, pendimethalin, and prodiamine) are susceptible to photodecomposition. However, once they are watered into the soil they are unaffected by further photodecomposition.[11]

Microbial decomposition

The most common means of pesticide degradation is the action of microorganisms found in soil and thatch. Microorganisms use the pesticide as a food source, resulting in pesticide degradation. Microorganisms also may alter the structure of the pesticide, usually resulting in detoxification and ultimately in further degradation.[11]

Environmental conditions significantly affect the activity of soil microbiological populations. Warm, moist, well-aerated soil with a pH of 6.5-7.0 encourages high microbial activity. Enhancing biological activity in the soil encourages faster pesticide breakdown and degradation.

Chemical degradation

The hydrolysis of pesticides can also be important. This process may be enhanced or reduced by the presence of mineral or organic absorbing surfaces. Further research will perhaps clarify some of these processes.[58]

RESPONSIBLE PESTICIDE APPLICATION PRACTICES

The first step in using any pesticide is to follow the directions exactly as stated on the container label. The label provides necessary information regarding proper product application and container disposal procedures. Labels are legal documents and are enforceable by law.

But before you even consider applying an insecticide or fungicide to a turf area, be sure that the apparent damage is indeed being caused by an insect or disease. Even if the damage is attributed to an insect or disease, it still may not be severe enough to warrant using a pesticide.

The same advice applies to weeds; their presence may only be indicative of other cultural conditions that need to be corrected. That's why it's so important that weeds first be properly identified before you take any kind of action. Certain types of weeds and lower population levels may not even justify a pesticide treatment.

Different pest population levels cause different levels of damage. Usually the higher the population level, the greater the damage. But the time of year can greatly influence the extent of damage as well. For example, a low insect pest population level early in the season (when many plants can be very sensitive to insect damage) may cause much more damage than a very high population later in the season when the plant is more mature and "tougher." This relationship between pest, pest population levels, time of year, and economic damage is the basis for an important pest management concept known as the economic threshold.

Following are some general guidelines regarding the use of economic pest damage threshold levels and general pesticide application practices that may minimize adverse impact on water quality.

Economic pest damage threshold levels

Although not used extensively with turf pests, the concept of threshold values for economic damage levels has been applied to some turf insect pests. This concept recognizes that a healthy turf can withstand a certain amount of insect damage without causing permanent damage. Even though some grass plants may be lost to the pest, a healthy turf has a relatively high degree of recoverability. After an attack, the remaining turf plants respond by quickly filling areas thinned or left open by the pest. Following are some suggested threshold values for three common Upper Midwest turf insects.[5]

White grubs. These are the larvae of the common May beetle or June bug. Damage caused by these root-feeding pests appear as irregular patches of yellowed or dead grass. Heavy infestations will loosen the sod so much that it can be rolled back; this type of damage becomes very apparent in July and August and is caused by large (third year) grubs. Damage caused by the smaller first or second year grubs is much less apparent, often making turf look wilted and water-starved. Checking for grubs should be done from mid-June through the middle of July. Look for them by rolling back the turf from a 1 square foot area of suspected white grub damage. If two to five grubs less than 1/2 inch in length (usually curled up in a "C" shape) are found per square foot, control may be needed. Grubs this size are probably first year grubs and don't cause much damage. However, second and third year grubs cause considerably more damage, so it's important to control them before they reach that stage. Fall treatments are ineffective as grubs move down into soil for the winter.

Bluegrass billbug. If you've had a history of problems with this pest and know what to look for (long-snouted, gray-to-black beetles with tapered abdomens and about 1/4 inch long), you may be prepared and able to treat the adult females during May when they are laying their eggs. This is the best time for control; however, it's also possible to control the immature larvae as they feed on the roots. To control the adults, apply an appropriate insecticide about 10 days after adults are sighted (about mid-May). As they mature, the small, plump whitish larvae eventually move from grass stems down into grass roots. If there are 10 larvae per square foot or more, control may be needed. Treatment is not effective after late July or early August as larvae move 1 to 2 inches into the soil to pupate.

Sod webworm. These are the larvae of adult moths, which are frequently called lawn moths. They feed on grass leaves at night and hide in silk-lined tunnels or burrows at night. Most of the damage is caused by the second generation. Check for them by flooding the suspected area with water to force worms to the surface for counting. This is best done in June and again in early August as there are two generations per year. If 15 or more worms per square yard are present, control may be necessary.

For more complete information on insect identification, life cycles, damage symptoms, and proper control practices of these and other turf insect pests, see reference 5 and consult with state and local Extension offices for current insect pest management recommendations.

Threshold values may be different for different turf situations. For example, tolerance to insect or disease damage on a golf green or high quality athletic field is lower than on golf course roughs or general lawn areas.

Economic threshold values have not been applied to weeds in turf areas. Common sense and how the area is used may dictate whether or not weed control is necessary. For example, a few weeds scattered throughout a general purpose turf do not pose a threat to the well-being of an established, healthy stand of grass. In home lawns, it may be practical to hand-remove the few weedy plants. High quality, high use turf areas such as golf greens or athletic fields may periodically require an herbicide treatment to maintain high aesthetic standards.

GENERAL APPLICATION PRACTICES

As with fertilizers, take extreme care to prevent the direct application of pesticides into surface water. Be alert, and be sure your equipment is working properly. Dumping pesticide-treated grass clippings on or near the shoreline may represent a potential pollution problem regarding both nutrients and pesticide residues.[58] It's best to leave clippings on the lawn where they'll be recycled.

Application timing

To minimize adverse environmental impacts while effectively eliminating pests, it's critical to properly time pesticide applications. The key is to treat when the pest is young and/or at a highly vulnerable stage. This will allow you to use a minimal amount of pesticide with maximum effectiveness. When weeds or insects are quite large and mature, greater amounts of pesticide are usually needed and even then may not be as effective. For example, it is relatively easy to control small, first-year dandelion rosettes with a minimal amount of herbicide. Larger, several-year-old dandelion plants have a greater capability to outgrow, and hence recover from small doses of herbicides. Where appropriate, small dandelion rosettes can be effectively hand removed and eliminated by removing the entire system. Similarly, treating diseases at early stages of infection is more prudent—and usually requires less fungicide than treating large, heavily infected areas.

Fall is the best time to control perennial broadleaf weeds. From mid-September to early October, these plants are actively growing and readily take up herbicides. As a result, a single lower rate herbicide application is usually effective. Since most other plants are either going dormant for the winter or have been removed from gardens and flower beds, there is also less chance for off-target plant injury. However, that doesn't mean we should be less careful. Even the best treatment and timing are no substitute for preventing problems in the first place.

Preventive pest control measures are more effective than waiting until a problem has begun, especially regarding disease. Such measures are necessary on high quality turfs—such as golf greens—where there is low tolerance for damage. Thus, turf managers increase their disease control effectiveness by watching for environmental conditions that favor disease development. They are able to refine their management techniques with new technologies in weather monitoring devices and turf disease diagnostic kits that both improves disease control effectiveness and reduces the need for pesticide applications. For example, applying lower label rates of fungicides when conditions are favorable for fungus invasion usually makes better use of the product, while still providing adequate control.

POST-APPLICATION IRRIGATION

Preemergent herbicides, typically used for controlling crabgrass and other annual weedy plants, must be moved into the soil surface to be effective. They affect the seed as it begins to germinate, before the plant emerges from the ground. Depending on the soil type, 1/4 to 1/2 inch of moisture should be applied following application of these products—about 1 to 2 hours of irrigation with most common lawn sprinklers.

Automatic irrigation systems may need to be appropriately adjusted. This not only puts the product where it will be the most effective, but moves the material far enough into the soil so it will not be carried away in runoff.

Insecticides and fungicides require similar post-application watering. This puts the product where it is most effective, reduces the chances of being moved off-site by runoff or leaching, and potentially reduces exposure to the material.[14,22,37]

Thatch can facilitate the breakdown of these materials, potentially reducing their effectiveness, but also shortening their persistence in the environment.[14,36] Pesticide label directions indicate whether or not post-application irrigation is needed.

APPLICATION WATER VOLUME

It is not necessary to thoroughly drench an area with a herbicide to achieve satisfactory weed control. This may be wasteful of both water and herbicide, and may move the herbicide beyond the plants and into soil where it is prone to leaching, or where plant cover is sparse and the herbicide could potentially run off. Spraying to wet the foliage is sufficient to get enough herbicide into the plant to be effective. Again, follow label directions for both proper mixing and proper post-application watering.

Protecting surface water and groundwater is not something to be taken lightly. But neglecting turf areas for fear of introducing nutrients and pesticides into water supplies is not a way to protect these resources. Properly maintaining turfed areas with appropriate but modest use of fertilizers and pesticides will do more to protect water resources than to hurt them.

Reference Listing

1. Agnew, M.L. 1989. Groundwater, turf management and public perception. Iowa Turfgrass Grower. March. pp. 4,5,6.
2. Allen, P.S., and White, D.B. 1990. Lawn clipping management. AG-FO-3915. Minnesota Extension Service. University of Minnesota. 4 pp.
3. Anderson, J.L., Balogh, J.C., and Waggoner, M. 1989. Soil Conservation Service procedure manual: Development of standards and specifications for nutrient and pest management. Sections I & II. USDA Soil Conservation Service. State Nutrient and Pest Management Standards and Specification Workshop, St. Paul, MN, July. 453 pp.
4. Anon. 1990. Researching maintenance. Grounds Maintenance. October. p. 1.
5. Ascerno, M.E. 1986. Controlling lawn and turf insects. AG-FO-1008. Minnesota Extension Service. University of Minnesota. 4 pp.
6. Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall, Inc. Englewood Cliffs, N.J. 658 pp.
7. Beard, J.B. 1987. Late season fertilization. Grounds Maintenance. August. p. 64.
8. Beard, J.B. 1987. Nitrogen: apply less more often. Grounds Maintenance. June. pp. 26,28,30.
9. Becker, R.L., Herzfeld, D., Ostlie, K.R., and Stamm-Katovich, E.J. 1989. Pesticides: Surface runoff, leaching, and exposure concerns. AG-BU-3911. Minnesota Extension Service. University of Minnesota. 32 pp.
10. Brach, J. 1989. Protecting water quality in urban areas—best management practices for Minnesota. Minnesota Pollution Control Agency, Division of Water Quality.
11. Branham, B.E. 1989. Pesticide fate in turf. Iowa Turfgrass Grower. March. pp. 2-4.
12. Carrow, R. N. 1985. Soil/Water relationships in turfgrass. In Gibeault, V. A., and Cockerham, S. T. (eds.) Turfgrass Water Conservation. University of California, Riverside. Division of Agriculture and Natural Resources. pp. 85-102.
13. Cohen, S.Z. 1990. The Cape Cod study. Golf Course Mgt. February. pp. 26,28,32,34,38,40,42,44.
14. Cooper, R.J. 1990. Evaluating the runoff and leaching potential of turfgrass pesticides. Golf Course Mgt. February. pp. 6,7,10,12,14,16.
15. Daniel, T. C., and Schneider, R. R. 1979. Nonpoint pollution: problem assessment and remedial measures; economic and planning considerations for designing control methods. In Beatty, M.T., Peterson, G.W., and Swindale, L.D. (eds.). Planning the uses and management of land. American Society of Agronomy. Madison, Wisconsin. pp. 829-852.
16. Daniel, W.H., and Freeborg, R.P. 1979. Turf managers handbook. Harvest Publishing Co. Cleveland, Ohio. 424 pp.
17. Foote, L. E., Kill, D.L., and Bolland, A.H. 1970. Erosion prevention and turf establishment manual. Office of Materials Construction Division. Minnesota Department of Highways. 44 pp.
18. Gold, A.J., DeRagon, W.R., Sullivan, W.M., and Lemunyon, J.L. 1990. Nitrate-nitrogen losses to groundwater from rural and suburban land uses. J. Soil and Water Cons. 45(2): 305-310.
19. Gold, A.J., Morton, T.G., Sullivan, W.M., and McClory, J. 1988. Leaching of 2,4-D and dicamba from home lawns. Water, Air, and Soil Pollution 37: 121-129.
20. Gold, A.J., Sullivan, W.M., and Hull, R.J. 1989. Influence of fertilization and irrigation practices on waterborne nitrogen losses from turfgrass. In Leslie, A.R., and Metcalf, R.L. Integrated pest management for turfgrass and ornamentals. Office of Pesticide Programs, 1989-625-030 U.S. Environmental Protection Agency. Washington, D.C. pp. 143-152.
21. Gross, C.M., Angle, J.S., and Welterlen, M.S. 1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19: 663-668.
22. Harrison, S.A., Watschke, T.L., and Hamilton, G. 1989. Nutrients and pesticides in runoff and leachate from irrigated turfgrass sites. Agronomy Abstracts. p. 158.
23. Horsley, S.W., and Moser, J.A. 1990. Monitoring ground water for pesticides at a golf course—a case study on Cape Cod, Massachusetts. Ground Water Monitoring Review. Winter. pp. 101-108.
24. Hummel, N.N., Jr., 1990. Late season fertilization. Landscape Management. August. pp. 28,30,32,33.
25. Kahler, K.E. 1990. Golf courses' groundwater passes testing for pesticides. Golf Course Mgt. December. pp. 42,44,46,47.
26. Koski, A.J. 1991. Early season fertilization. Landscape Management. February. 38,40,42,44.
27. Krause, A.A., and Niemczyk, H.D. 1989. Vertical mobility of six preemergent herbicides applied to turfgrass. Agronomy Abstracts. p. 160.
28. Leslie, A.R. 1989. Societal problems associated with pesticide use in the urban sector. In Leslie, A.R. and Metcalf, R.L. Integrated pest management for turfgrass and ornamentals. Office of Pesticide Programs, 1989-625-030 U.S. Environmental Protection Agency. Washington, D.C. pp. 51-54.
29. Leslie, A.R., and Knoop, W. 1989. Societal benefits of conservation oriented management of turfgrass in home lawns. In Leslie, A.R., and Metcalf, R.L. Integrated pest management for turfgrass and ornamentals. Office of Pesticide Programs, 1989-625-030 U. S. Environmental Protection Agency. Washington, D.C. pp. 93-96.
30. Lundquist, J. B. 1975. A primer on

limnology. Limnological Research Center. University of Minnesota. Contribution No. 142. Public Report Series No. 1. 28 pp.

31. Mancino, C.F. 1991. Nitrate and ammonium concentrations in soil leachate and N leaching losses from fertilizers applied to turfgrass. Golf Course Mgt. February. pp. 66,68,70,72.

32. Mancino, C.F., and Troll, J. 1990. Nitrate and ammonium leaching losses from N fertilizers applied to ÔPenncross' creeping bentgrass. HortScience 25(2): 194-196.

33. Martin, D.P. 1970. The composition of turfgrass thatch and the influence of several materials to increase thatch decomposition. M.S. Thesis, Michigan State University.

34. McIver, T. 1990. Liquid vs. dry: The pendelum swings. Landscape Management. August. pp. 26-27.

35. Morton, T.G., Gold, A.J., and Sullivan, W.M. 1988. Influence of overwatering and fertilization on nitrogen losses from home lawns. J. Environ. Qual. 17: 124-130.

36. Niemczyk, H.D., and Krause, A. 1989. Degradation and mobility of insecticides applied to turfgrasses. Agronomy Abstracts. p. 162.

37. Niemczyk, H.D., and Krueger, H.R. 1987. Persistence and mobility of isazofos in turfgrass thatch and soil. J. Econ. Entomol. 80: 950-952.

38. Petrovic, A.M. 1989. Golf course management and nitrates in groundwater. Golf Course Mgt. September. pp. 54,56-58,60,64.

39. Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19: 1-14.

40. Potter, D.A., Cockfield, S.D., and Morris, T.A. 1989. Ecological side effects of pesticide and fertilizer use on turfgrass. In Leslie, A.R., and Metcalf, R.L. Integrated pest management for turfgrass and ornamentals. Office of Pesticide Programs, 1989-625-030 U.S. Environmental Protection Agency. Washington, D.C. pp. 33-44.

41. Rehm, G. 1987. Management of soils in southwestern Minnesota—a correspondence course. Unit 2: understanding phosphorus and potassium. AG-FO-3333. Minnesota Extension Service. University of Minnesota. 4 pp.

42. Rieke, P.E., and Ellis, B.G. 1974. Effects of nitrogen fertilization on nitrate movements under turfgrass. In Proc. 2nd Int. Turfgrass Res. Conf. pp. 121-130.

43. Roberts, E. C. 1990. A view from the grassroots up. Nursery Business-Retailer Edition. July. pp. 40,41,45,63.

44. Roberts, E.C., and Roberts, B.C. Lawn and sports turf benefits. The Lawn Institute. Pleasant Hill, Tennessee. 31 pp.

45. Rosen, C.J., Taylor, D.H., and White, D.B. 1990 Preventing pollution problems from lawn and garden fertilizers. AG-FS-2923-A. Minnesota Extension Service. University of Minnesota.

46. Shapiro, J., and Pfannkuch, Hans-Olaf. 1973. The Minneapolis Chain of Lakes—a study of urban drainage and its effects 1971-1973. Interim Report No. 9. Limnological Research Center. University of Minnesota.

47. Sharpley, A.N., and Menzel, R. G. 1987. The impact of soil and fertilizer phosphorus on the environment. Adv. in Agron. 41: 297-324.

48. Stahnke, G.K., Shea, P.J., Shearman, R.C., Stougaard, R.N., and Tupy, D.R. 1989. Dissipation of pendimethalin in Kentucky bluegrass tissue, thatch and soil. Agronomy Abstracts. p. 166.

49. Stahnke, G.K., Shea, P.J., Tupy, D.R., and Shearman, R.C. 1988. Movement and dissipation of pendimethalin in Kentucky bluegrass turf. Agronomy Abstracts. p. 156.

50. Starr, J.L., and DeRoo, H.C. 1981. The fate of nitrogen fertilizer applied to turfgrass. Crop Sci. 21(4): 531-536.

51. Taylor, D.H., Rosen, C.J., and White, D.B. 1990. Fertilizing lawns. AG-FO-3338-B. Minnesota Extension Service. University of Minnesota. 4 pp.

52. Timmons, D.R., Holt, R.F., and Latterell, J.J. 1970. Leaching of crop residues as a source of nutrients in surface runoff water. Water Resour. Res. 6(5): 1367-1375.

53. Tisdale, S.L., and Nelson, W.L. 1966. Soil fertility and fertilizers, 2nd ed. The Macmillan Co. New York, New York. 694 pp.

54. Turgeon, A.J. 1980. Turfgrass management. Reston Publishing Co. Reston, Virginia. 391 pp.

55. Waddington, D.V. 1985. The fate of nitrogen applied to turf. Grounds Maintenance. November. pp. 14,16,18,22.

56. Walker, W.J., Balogh, J.C., Kenna, M.P., and Snow, J.T. 1990. Environmental issues related to golf course construction and management. United States Golf Association: Green Section. 378 pp.

57. Watschke, T.L. 1990. The environmental benefits of turfgrass and their impact on the greenhouse effect. Golf Course Mgt. February. pp. 150-154.

58. Watschke, T.L. 1990. The environmental fate of pesticides. Golf Course Mgt. February. pp. 18,22,24.

59. Watschke, T.L., Harrison, S., and Hamilton, G. 1988. Movement of nutrients and pesticides in runoff from turfed slopes. Agronomy Abstracts. p. 157.

60. Watschke, T.L., Harrison, S., and Hamilton, G.W. 1989. Does fertilizer/pesticide use on a golf course put water resources in peril? USGA Green Sect. Record. May/June. pp. 5-8.

61. Welterlen, M.J., Gross, C.M., Angle, J.S., and Hill, R.L. 1989. Surface runoff from turf. In Leslie, A.R., and Metcalf, R.L. Integrated pest management for turfgrass and ornamentals. Office of Pesticide Programs, 1989-625-030 U.S. Environmental Protection Agency. Washington, D.C. pp. 153-160.

62. Wetzel, R.G. 1983. Limnology, 2nd ed. Saunders College Publishing. 858 pp.

http://www.mes.umn.edu/

Additional copies of this item can be ordered from the University of Minnesota Extension Service Distribution Center, 20 Coffey Hall, 1420 Eckles Avenue, St. Paul, MN 55108-6069, e-mail: order@dc.mes.umn.edu or credit card orders at 800-876-8636 or 624-4900 (local calls).

Printed on recycled paper with minimum of 10% postconsumer waste, using agribased inks.

Produced by the Educational Development System, University of Minnesota Extension Service.