CORNELL UNIVERSITY TURFGRASS TIMES

CUTT

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The Emperor's Soil: The Naked Truth

The turf industry is obsessed with soil. Millions of research dollars are spent each year to explore the physical and chemical aspects of soil. For example, the United States Golf Association (USGA) has spent millions simply on understanding and refining specifications for putting green construction.

The search for the "right" soil, sand or amendment has spurred many new industries. Sand companies, organic and inorganic amendment companies, blenders, and testing labs have all flourished in this soil-obsessed world.

Nailed by Specs

USGA specs are used as a guide to "ensure" success, but they can easily double as a hammer with which to nail blame should greens fail. In general, it is widely agreed that the specs focus on drainage with little regard for chemical properties.

The increased number of sand-based rootzones has raised questions on proper fertility that are understood by researching soil chemistry. Private soil chemical testing companies have a network of consultants that promote testing, interpret the numbers and make recommendations.

Though soil chemical analyses often are informative and accurate, consultants sometimes complicate the data with their interpretations, or opinions, in an effort to help turf managers better understand the research. By putting "spin," as it's referred to in political parlance, on the data, leaps of faith are taken without supportive research that calibrates plant response to soil nutrient level.

Favoring the Emperor

When I ask turf managers what they know about certain agronomic practices and chemical treatments, they often regurgitate what they have been told by consultants—though they don't understand the information. When this happens I am reminded of the story entitled "The Emperor's New Suit" by Hans Christian Andersen. In the story, written in 1837, two swindlers persuade an emperor with an obsession for fine clothing that "they could manufacture the finest cloth to be imagined, but the clothes made of their material possessed the

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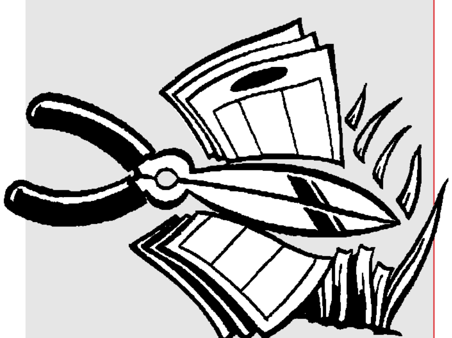
Clippings

Ph.D. candidates Zachary Easton and Micah Woods were winners in the Crop Science Society of America graduate paper contest.

Frank Rossi was named the 2004 outstanding young alumnus from SUNY Cobleskill.

The New York Agricultural Statistics Service has published the first-of-its-kind New York Turfgrass Survey on their web site, http://www.nass.usda.gov/ny.

Nathan Rudgers named 2004 "Friend of the Green Industry" by NYSTA.



Cornell Students Recognized Best!

Turfgrass Ph.D. candidates Zachary Easton (working with Marty Petrovic) and Micah Woods (working with Frank Rossi) won 3rd and 1st place respectively in the Crop Science Society of America turfgrass research division graduate paper contest. More than 50 graduate students were in the contest and to have two students from the same university emerge as winners demonstrates Cornell University's innovative approach to research and the quality of Cornell's students.

Rossi Named Outstanding Alumnus

Frank Rossi was named the 2004 outstanding young alumnus from SUNY Cobleskill at the 2004 New York State Turf and Grounds Exposition in Rochester, NY on November 17. Rossi graduated from Cobleskill in 1982 with an AAS degree in Agronomy under the tutelage of long time Cobleskill professor Bob Emmons. SUNY Cobleskill's president noted that, "Frank embodies all that is unique about Cobleskill and has regularly given back to the school with his time and expertise."

NY Turf Survey Released

The New York Agricultural Statistics Service (NASS) has published the 80-page report, "Turfgrass Final Publication" on their web site, http://www.nass.usda.gov/ny. It can be accessed by clicking "Special Surveys" on the NASS home page. Copies will be mailed to NYSTA members. The New York Turfgrass Survey is sponsored by the New York State Turfgrass Association and the New York State Department of Agriculture and Markets in cooperation with the New York Agricultural Statistics Service.

The newly released survey, which has been in the planning and implementation stages for the past five years, is the first of its kind to evaluate the magnitude and economic importance of the turfgrass industry in New York State. This important data will position the turfgrass industry as a growing agricultural commodity in New York State and enable the public, industry and government to work together to ensure its continued growth.

Ag & Markets Commissioner Chosen as "Friend"

The New York State Turfgrass Association (NYSTA) has awarded Nathan Rudgers, Commissioner of the New York State Department of Agriculture and Markets, with the "Friend of the Green Industry" award. This award is given to individuals who have excelled in support of the turfgrass industry.

Commissioner Rudgers was recognized for pledging his department's support of the New York Turfgrass Survey in 2001 and his foresight in recognizing the importance of documenting the economic value of the turfgrass industry. The award was presented at NYSTA's annual Turf & Grounds Exposition, "Economics and the Environment— Surveying the Landscape," at the Rochester Riverside Convention Center in Rochester, NY.

Send Us A Letter

We enjoy receiving letters from readers reacting to the articles and information presented in *CUTT.* Encouraging a free-flowing, two-way communication between our readers and Cornell's Turfgrass Team can only make *CUTT* a better, more relevant publication.

Send your comments to *Cornell University Turfgrass Times*, 134A Plant Science Building, Cornell University, Ithaca, NY 14853, or via email to fsr3@cornell.edu.

Nitrogen Uptake in Kentucky Bluegrass

Nitrate leaching into ground water is a major concern for the turfgrass manager. The nitrogen uptake rate (NUR) for Kentucky bluegrass plants is an important factor in selecting plants that can reduce the amount of nitrate leached into ground water. Since nitrate leaching is of particular concern during establishment, researchers at the University of Rhode Island studied six cultivars of Kentucky bluegrass at the seedling, as well as mature plant, stage.

In addition to comparing NURs among and within the cultivars, the study also investigated the relationship between seedling NUR and mature plant NUR. The ability to select cultivars with high mature plant NUR based on seedling NUR would decrease the amount of time required for selection and development.

The six cultivars (Blacksburg, Barzan, Conni, Dawn, Eclipse, Gnome) were screened for NUR beginning at 30 days after seeding. Seedling NUR was positively correlated with total length and total area of leaves and roots of the seedlings. There were significant differences in seedling NUR both among and within the cultivars. The removal of shoot tissue significantly and immediately reduced NUR, but rates generally increased to initial levels within a week.

For the most part, however, the results did not show a significant correlation between seedling NUR and mature plant NUR. Therefore, seedling NUR may not be a good predictor of mature plant NUR in all cases. This is likely due to the fact that mature plants have characteristics that the seedlings do not, such as the ability to produce tillers and rhizomes, both of which would influence NUR.

With the issue of water quality being such a high priority in this industry, growing turfgrass cultivars that are genetically programmed with high NURs is an important tool in reducing the risk of leaching.

From: Jiang, J., W.M. Sullivan. 2004. Nitrate uptake of seedling and mature Kentucky bluegrass plants. Crop Sci. 44:567-574.

Residential Fertilization Practices Surveyed

The scarcity of data on residential lawn care practices makes it difficult to evaluate fertilizer, pesticide and water use. With concern growing throughout the United States over surface and ground water contamination from both nutrients and pesticides, this information is critical for establishing sound turf management guidelines and educational outreach programs.

In an effort to characterize how turf fertilization practices in residential areas may contribute to water pollution, researchers at North Carolina State University conducted a survey in five North Carolina communities. Homeowners and lawn care companies were asked specific questions about how they fertilize lawns.

More than half of urban homeowners surveyed use fertilizer on turf. Some households used lawn care services, with the highest frequency of use occurring in the community with the highest median income. High and medium income households had significantly higher fertilizer rates than low-income households. Fertilization was based on soil testing for only 20% of the households, and none of the lawn care companies surveyed used soil tests on a routine basis.

Generally, fertilization rates for tall fescue lawns were appropriate, but for grasses with low N requirements, such as centipede grass, excess fertilizer was often applied. Both homeowners and lawn care services tended to fertilize during the wrong season. On average, only 52% of households removed fertilizers from impervious surfaces such as driveways and sidewalks.

The results of this study indicate areas of concern that can be addressed in order to reduce negative environmental impacts of fertilizer use. Surveys in other areas of the country would no doubt yield information necessary for educating people about safe lawn care practices in their own communities.

From: Osmond, D.L., D.H. Hardy. 2004. Characterization of turf practices in five North Carolina communities. J. Environ. Qual. 33:565-575.

CUTT

Scanning the Journals

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The Emperor's Soil

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I often feel like that young child, saying: "I don't understand the soil test information." As I inquire further, I find a cult-like theology of soil testing, with no basis in turfgrass science.

In spite of research showing that most soils with a pH above 6.5 do not need calcium and findings saying that applied potassium has no measurable effect on soil, turf managers continue to apply them.

Microbial populations during sand-based construction increase and diversify until turf is established, then they stabilize. Beyond this we know very little.

wonderful quality of being invisible to any man who was unfit for his office or unpardonably stupid."

Well, of course, no one wants to be out of favor with the emperor, who has bought into the scam, so everyone in the kingdom pretends to see the magnificent suit worn by their ruler. Eventually, an innocent child says, "But he has nothing on at all," and that comment leads everyone, including the emperor, to see the truth.

I often feel like that young child, saying: "I don't understand the soil test information." As I inquire further, I find a cult-like theology of soil testing, with no basis in turfgrass science. Many of the soil tests that confuse me often require additions of nutrients, principally calcium and potassium. Furthermore, I am surprised at how many times I see specious fertilizer recommendations from persons aligned with fertilizer companies based on the feed-the-soil approach.

One would think that the golf turf industry has an epidemic of calcium- and potassium-deficient soils. In spite of research showing that most soils with a pH above 6.5 do not need calcium and findings saying that applied potassium has no measurable effect on soil, turf managers continue to apply them. I can only assume these nutrients are being applied because the private soil-testing industry is promoting their application. I can find little or no independent university research that supports the widespread application of these nutrients; in fact most studies argue against their application in most cases.

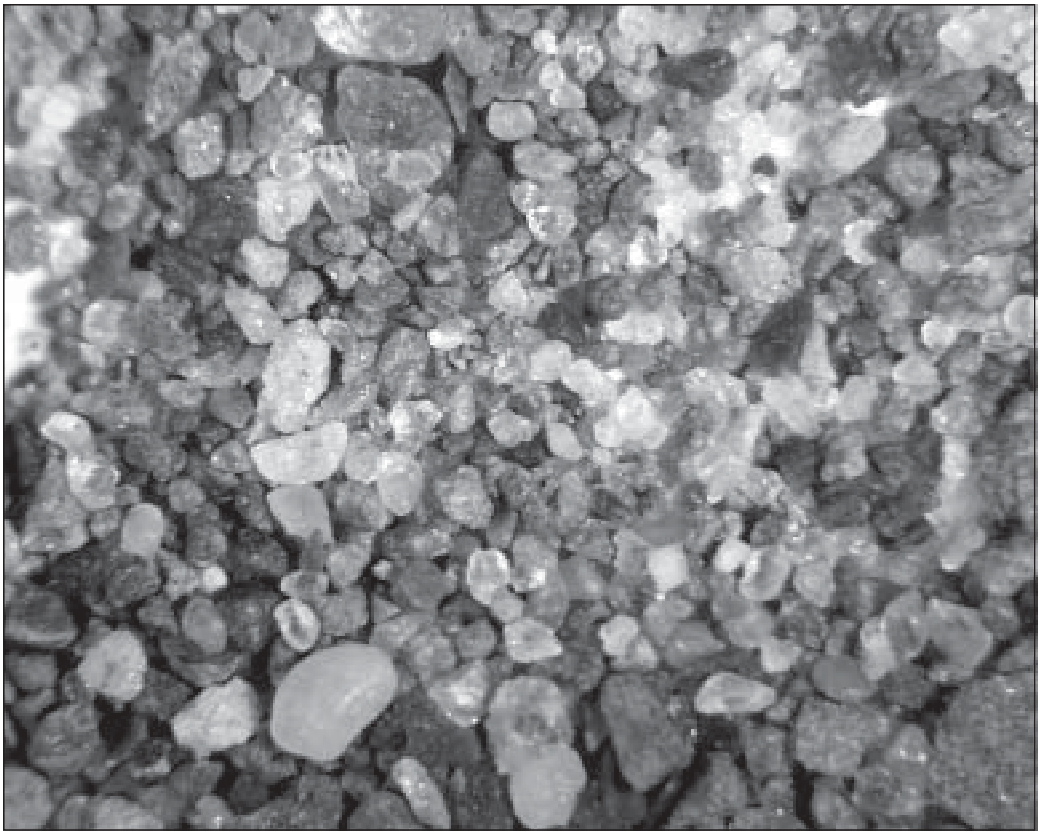
Soil Health

Apart from the physical and chemical aspects of soil, the biological aspects remain a black box. However, the concept of proper soil biology or soil health is emerging in the industry. I hear it touted in organic farming circles and in turf regions where pesticide restrictions are under consideration. Finding methods for manipulating soil microbial activity to create a healthy soil is "all the rage" in turf management systems.

My critical nature shapes my initial thoughts of skepticism. I explore the concept and find that we have been studying soil biology for many years in turf science. For example, several USGA-funded turfgrass research studies found no meaningful effect of pesticides on soil microbial activity. Microbial populations during sand-based construction increase and diversify until turf is established, then they stabilize. Beyond this we know very little.

The "emperor" factor in the soil health movement is the promotion of products or practices to manipulate soil microbes. Organic agriculture will accomplish this by incorporating large amounts of compost (a large source of microbes and microbe food [carbon]). This is

Sand-based rootzones can be created by straight sand top-dressing.



Sand derives its cation exchange capacity almost exclusively from organic matter.

all well and good except for two items: one, we barely understand what we are manipulating; and two, with the soil covered with turf it is difficult to get the compost applied at high levels, even if we knew what it would do.

Similar to soil chemical testing, I often see soil biological test results. Again, the numbers derived from the microbial assessments are solid. It is the interpretation of the results that defies reason. Leading microbiologists can hardly assess 5 percent of all the microbes in the soil. How can we in the scientific community claim to manipulate soil biology when we barely understand what is going on in the first place?

In the end this is a cautionary tale. I must be careful not to let my skepticism blind me to important innovations. At the same time, turf managers need to open their eyes to see if the empirical evidence they're presented with is the naked truth.

Frank S. Rossi, Ph.D.

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Can Soil Tests Predict Phosphorus Runoff Losses?

Program Spotlight

Areas of the Midwest have enacted laws and ordinances banning the application of phosphorus to home lawns without a soil test showing the need for the nutrient; New York State has considered similar legislation.

The use of soil testing to limit phosphorus fertilization will not necessarily reduce the environmental impact of the site for the range of soil phosphorus values found in this study.

In many freshwater systems, excessive inputs of phosphorus (P) lead to an increase in the occurrence of algal blooms which harms the body of water in many ways. Oxygen is removed from the water, killing fish; drinking water quality deteriorates; and the lake or river's recreational value is compromised.

Phosphorus is transported to bodies of water during spring snow melt and rainstorms through runoff. Runoff from areas of bare soil (agricultural land and construction sites) can transport significant amounts of soil to surface water. Because P is relatively immobile and tends to accumulate in the upper soil profile, the P lost from these areas is proportional to the amount of soil test P. In agricultural settings, best management practices for meeting water quality goals include maintaining soil P at levels that meet crop needs but below certain environmental thresholds.

Recently, attention has been turned to reducing P losses from urban settings as a way to improve the quality of our lakes, streams and rivers. Although P losses from turfgrass areas have been found to be relatively low compared to agricultural sources, turfgrass areas represent a significant and ever-increasing fraction of land in most watersheds and are subsequently a potentially important source of P in urban runoff.

Areas of the Midwest have enacted laws and ordinances banning the application of P to home lawns without a soil test showing the need for the nutrient, and New York State has considered similar legislation. All prior lawn P fertilizer bans have allowed P applications during the first year of establishment or with a soil test demonstrating need. These exceptions are based on two suppositions: first, the source of the P lost from turfgrass is mainly from the fertilizer particle or the P in the soil, neglecting any losses of P from the turfgrass tissue or thatch layer; and secondly, that the agronomic need for P is somehow related to an environmental soil P threshold. We know from previous research that environmental thresholds for agricultural soils are commonly 2-3 times greater than the soil test P level required to meet plant needs.

The Cornell Study

During fall 2003, a study conducted at the Cornell University Turf and Landscape Research Center examined the relationship between soil P and runoff P from turfgrass. A previous study examining the effect of various fertilizer applications on runoff created an area with a wide range of soil P levels. Runoff was caused using a rainfall simulator and a runoff sample was collected and analyzed for dissolved P content. Sod was stripped from each plot and runoff was again forced and collected from the bare soil. On each plot, the soil was sampled, and soil P analyzed (based on the Morgan soil test extraction method, the standard procedure in New York at the Cornell Soil Testing Laboratory).

Table 1 shows the results of the experiment. We observed similar concentrations of P in runoff from turfgrass and bare soil. However, when the sod was stripped the infiltration rate decreased by a factor of 3, resulting in a lower P loss (load) from the turfgrassed areas. The P load is calculated by multiplying the concentration of P in the runoff by the total amount of runoff. Phosphorus loads can be used to assess the environmental impact of a site. In this case, the turf area reduced the environmental impact compared to bare soil by reducing the amount of runoff produced.

In this study, the soil test P value for the site was a good indicator of the P load in runoff from bare soil, but the same cannot be said for turfgrass areas. Therefore, the use of soil testing to limit P fertilization will not necessarily reduce the environmental impact of the site for the range of soil P values found in this study. We are continuing to examine the relationship between soil P and runoff P, as well as searching for other factors that can be used to accurately assess the potential for P loss from turfgrass areas.

Doug Soldat

CUTT

The Mugwort Story: Dealing With Invasive Weeds

The invasive perennial weed mugwort (*Artemisia vulgaris* L.) spreads primarily through rhizome fragments in disturbed habitats, and more recently, natural areas. The invasion and subsequent spread of this rhizomatous weed often leads to dense monospecific stands, excluding native vegetation and reducing overall biodiversity.

This study reports the rates and mechanisms of vegetative proliferation of two mugwort populations (ITH-1 and ITH-2) over three growing seasons (2001-2003) under a disturbed fallow field habitat and a ryegrass (*Lolium* spp.) turfgrass field; fields were either mowed monthly or had no mowing (2 pops x 2 habitats x 2 management treatments x 3 seasons).

Over the three-year growing period the two mugwort populations experienced exponential growth with respect to total ramet number, with the ITH-2 population generating significantly more ramets than ITH-1 in both habitats. However, ramet numbers between the two habitats differed dramatically, with an average of between 550 and 925 in the fallow field and 90 to 550 in the turfgrass field. This difference shows the variation in invasive strategy (rates of spread) between the populations and between the mowing treatments. Monthly mowing had a much greater effect on treatments in the turfgrass field than in the fallow field, with total ramet number below 100 (500 for non-mowed) versus the fallow field where mowing reduced total ramet number by only 100.

These mugwort populations collected from Ithaca, NY, which were maintained identically in a landscape previous to the experiment, are showing major phenotypic differences in lateral spread, total ramet production, average height, biomass, and response to mowing. This is important both for testing invasive potential in obligate clonally reproducing invasive species, as well as examining phenotypic (and likely genotypic) variation within a species.

Jacob Barney

Please Note:

The mail address for CUTT has changed. Please note the new address:

Cornell University Turfgrass Times, 134A Plant Science Building, Cornell University, Ithaca, NY 14853

Table 1. Effect of turfgrass on dissolved P concentrations, infiltration rate, and P load.

Observation	Turfgrass	Bare Soil
Mean P concentration, mg/L	0.09	0.09
Mean infiltration rate, cm/hr (in/hr)	38 (15.0)	10 (3.9)
Mean Runoff Volume, cm(in)	3.6 (1.4)	6.4 (2.5)
Mean P load, kg/ha(lbs./acre)	0.35 (0.31)	0.56 (0.50)

Program Spotlight

The invasion and subsequent spread of this rhizomatous weed often leads to dense monospecific stands, excluding native vegetation and reducing overall biodiversity.

Monthly mowing had a much greater effect on treatments in the turfgrass field than in the fallow field.

Turfgrass Management and Water Quality

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Burrows may increase leachate and soil infiltration rate, reducing runoff, but they have been shown by Binet and Le Bayon to increase sediment and dissolved phosphorus runoff from castings left on the soil surface.

in CEC, high organic matter, unsaturated conditions, or large microbe populations can be very effective at removing chemicals from solution. However, compounds such as NO_3^- are mobile, easily transported with water and represent a potential threat to ground water, even in soils with the above characteristics. Phosphorus can be mobile in sandy soils because of a lack of binding sites, but can also be bound tightly with the correct factors in place. In a study by Strock and Cassel, 70% of effluent transported through a profile was transported through macropores, which effectively negates any benefits obtained with using a finer textured soil.

Macropores

Leaching via macropore flow represents the most probable pathway for nutrients and pesticides to reach groundwater. Shipitalo and Gibbs measured macropores created by earthworms extending >1 m in to the soil profile, and some were directly connected to tile drains allowing for rapid water movement. Burrows may increase leachate and soil infiltration rate, reducing runoff, but they have been shown by Binet and Le Bayon to increase sediment and dissolved P runoff from castings left on the soil surface. Macropores created by earthworms were found to increase in compacted soils by as much as 50%, and were produced up to 3.5 times faster during wet periods.

Depending on soil type and management, these macropores can remain active for a long period of time. Soils with higher clay content and no-till cultivation have a higher abundance of macropores which can remain able to conduct flow for years. In their study, Shipitalo and Gibbs found that these burrows were capable of transmitting swine effluent un-attenuated to tile drains. However, Pote et al noted a reduction in the infiltration rate due to macropore clogging from swine manure application. They also found that a high infiltration rate not only reduced nutrient loads in runoff, but concentrations as well.

Macropores clearly have the ability to affect the transport of contaminants. Their presence in the soil profile can be both beneficial in that they will increase the infiltration rate, reducing runoff, and increasing aeration, but they will also speed the transport of contaminants to groundwater supplies. The effect of macropores on preferential flow can vary with

Macropores and fingers only contribute to solute movement when the soil is close to saturation. As the soil wets, more of the macropores will contribute to flow.

Cornell University runoff plot collection areas.

time. Linde et al. found that the infiltration rate of the soil varied with time, increasing because of root channeling and turnover. Likely, the soil exhibited greater infiltration at higher moisture content due in part to the initiation of macropore flow at the higher moisture content. Initially wet soils have shown much faster convergence to macropore or preferential flow because less water is required to saturate the soil.

Soils containing macropores can function like soils with a uniform distribution when unsaturated. Kung et al found that as the soil water content decreases, the adsorption of solutes increased due to the reduction of macropore flow and greater contact with the soil matrix. Timlin et al. found macropores to be responsible for the movement of strongly adsorbed tracers which otherwise would have remained in the upper region of the soil profile. Steenhuis et al. detected 2,4-D levels of 145 $\mu g\ L^{-1}$ in drain tiles buried at 80 cm, which was attributed to preferential macropore flow. Matrix flow would not have carried 2,4-D as deeply or at as high a concentration as preferential flow was capable of.

Fingers

Finger flow is another common pathway through which nutrients and pesticides may rapidly enter ground water. Fingers form in sandy soil due to an instability in the wetting front from increased hydraulic conductivity with depth, water repellent soils, or air entrapment. Finger and macropore flow are very similar, and ultimately both have the potential to transmit nutrients deep into the soil profile, beyond the reach of the roots, and microbes, to attenuate them. Fingers allow solutes to bypass the soil matrix, reducing attenuation. Macropores and fingers only contribute to solute movement when the soil is close to saturation. As the soil wets, more of the macropores will contribute to flow.

Lee measured infiltrations rates on soil containing earthworm burrows to be up to 10 times more rapid than soils with no burrows. However, in a study by Linde et al., worms were found to have no effect on the infiltration rate. Clearly their effect is site specific.

Many of the lysimeter studies referenced in the preceding sections contained soils that were screened and repacked into the lysimeters. This practice effectively removes the macropores from the soil. Flow in these lysimeters would be assumed to be flowing uniformly through the soil matrix. Greater interaction of solutes with the soil matrix allows adsorbed solutes to be bound or retarded much more quickly. This explains the low concentrations of nutrients and pesticides seen in drainage from these lysimeters.

Water moving through the soil profile utilizes multiple pathways. Movement pathways include finger flow, macropore flow, and matrix flow. Fingers form following initial infiltration of water and are responsible for transmitting contaminants very deeply into the soil profile. Macropores can form as a result of root growth and die back, worm movement, or the swell/shrink, freeze/thaw cycle in soils with clay.

The Benefits of Turf

Turf clearly has the ability to attenuate harmful nutrients and pesticides. The high evapotranspiration rate, rapid growth and wide ecological range make them ideally suited for remediation. Best management practices to reduce nutrient and pesticide runoff, explored by Baird et al., determined that vegetative buffers would reduce nutrient and chemical concentrations in runoff and that taller buffers worked better than shorter buffers. In addition, excess application of water-soluble fertilizers and pesticides on saturated soils should be avoided.

The use of turf and grass filter strips to reduce N, P and sediments was studied by Daniels and Gilliam who found that a grass filter alone was more effective at reducing N, P and sediments than a wider grass and riparian filter, but that removal rates for filters varied widely depending on the antecedent moisture. Filter effectiveness was mainly a factor of its ability to control runoff. If runoff could be slowed, and allowed to infiltrate, nutrients were attenuated. Gross et al. recorded a 600% decrease in sediment loss from turfgrass over bare soil. Cole et al. found that buffers were effective in removing pesticides and nutrients. However, buffers are generally less effective at removing P, due in part to buffer P saturation.

Comparatively, Casey and Kline found that riparian wetlands were effective at removing both NO_3^- by 80% and PO_4^{3-} by 74% from runoff from golf courses. However, they do mention that PO_4^{3-} attenuation may be reduced due to P saturation in the wetland, leaving only plant uptake as the primary means of P removal. Conversely, Tate et al. found that buffers were ineffective in removing NO_3^- from runoff.

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The use of turf and grass filter strips to reduce nitrogen, phosphorus and sediments was studied by Daniels and Gilliam who found that a grass filter alone was more effective at reducing nitrogen, phosphorus and sediments than a wider grass and riparian filter, but that removal rates for filters varied widely depending on the antecedent moisture.

Baird et al. discovered that a turfgrass buffer reduced pesticide runoff through a number of factors, including dilution, reduced runoff velocities, physical filtering, and increased infiltration.

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Turfgrass Management and Water Quality

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High energy storms can overwhelm the filter and reduce effectiveness. In another study, buffers reduced nitrates as much as 80%.

Soil type (sand, silt and clay content), biotic organism population, vegetation type and influence, slope, depth to restrictive layer, location, and macro porosity can all influence nutrient and pesticide transport.

Soils at the hill slope toe will have a higher moisture content than at the top of the slope, allowing them to, on average, saturate faster and produce greater runoff.

Grass hedges have been shown to exhibit high trapping efficiency, >90%, for P, NO_3^-, NH_4^+, and Atrazine by Barfiled et al. Eghball et al. recorded the greatest reductions in nutrient concentrations from the more soluble nutrients, such as NO_3^- and NH_4^+. The transition zone, from shortcut highly managed turf to a buffer has been shown to be of great importance in trapping sediment and, hence, the compounds associated with them. Gilley et al. show that the backwater conditions in the transition zone will create a hydraulic head forcing water to enter the profile and sediments to settle out. Baird et al. discovered that a turfgrass buffer reduced pesticide runoff through a number of factors, including dilution, reduced runoff velocities, physical filtering, and increased infiltration.

Wetlands

Many golf courses, developments and municipalities utilize wetlands to filter and remove contaminants from water. Wetlands have the ability to remove or reduce concentrations of NO_3^--N in the greatest quantities. Limited removal of PO_4^{3-}-P, heavy metals, organics, pathogens, and sediment can also be expected. Woltemade recorded N inflow levels of up to 13 mg L^{-1}, which were reduced up to 85% during residence time in the wetland. For P removal to be effective, longer residence times, 15 to 25 days, may be required. P removal is primarily accomplished by adsorption to soil particles. While vegetation type is important, Hammer found that it is the ecosystem the vegetation creates that is more important. The vegetation should create an environment beneficial to microbial populations, which will allow oxygen movement to the root system, increasing remediation rates.

Grass filters have the potential to greatly reduce nutrient and pesticide levels and loads in surface water. Nitrate, P and sediment reductions of 50-90% were recorded. However, they also discovered that high energy storms can overwhelm the filter and reduce effectiveness. In another study, buffers reduced nitrates as much as 80%.

Hydrology

Hill slope hydrology and its interaction with vegetation is a complicated subject, one which depends greatly on local parameters. Simply applying fertilizers or pesticides at the correct rate and time will not necessarily prevent contamination of water supplies. Soil type (sand, silt and clay content), biotic organism population, vegetation type and influence, slope, depth to restrictive layer, location, and macro porosity can all influence nutrient and pesticide transport.

In the northeast and elsewhere with hardpan soils, hill slope soils are normally shallow (low depth to restrictive layer) and prone to runoff caused by saturation excess. These localized saturated areas area associated with the bottom of hill slopes where subsurface flow converges either due to a slope change (reduces hydraulic conductivity) or a decrease in the depth to the restrictive layer. As a result, soils at the hill slope toe will have a higher moisture content than at the top of the slope, allowing them to, on average, saturate faster and produce greater runoff. Frankenberger et al. show that moisture contents on hill slopes can vary by as much as 35% from top to bottom.

In other cases, soils may exhibit variable porosity based on moisture content. Soils with higher moisture contents should show greater porosity, as larger pores become active. However, greater porosity does not indicate that the soils will exhibit greater hydraulic conductivity, unless the pores are interconnected, or very large (macropores).

Preferential Flow

Preferential flow can have a varying impact on the transport of adsorbed and non-adsorbed compounds. It has been shown that these pathways become active at moisture contents approaching saturation and that they can transmit very strongly adsorbed chemicals. In an experiment by Kung et al., a very strongly adsorbed tracer was detected in a tile line buried at 90 cm 24 min after the onset of irrigation. Non-adsorbed tracers were detected even more quickly. However, they discovered that the tails of the breakthrough curves (BTC) for the adsorbed and non-adsorbed chemicals differed markedly. The BTC of the adsorbed compound trailed off much more quickly after irrigation stopped because macropore flow was reduced as the moisture content decreased, causing greater interaction of the compound with the soil matrix.

Nitrate applied to wet soil was shown to leach at levels as high as 20%, whereas when applied to an initially dry soil, levels were only 7%, further evidence that wet soils exhibited greater macropore flow. It was also found that non-adsorbed and adsorbed tracers moved at essentially the same rate through saturated soil, indicating that the convective dispersive equation was not able to capture leaching events well in the presence of macropores.

Wilkinson and Blevins found preferential flow to account for 35% of the overall flow and a significant portion of the Br tracer transport through a claypan. From this, they surmised that claypan soils would do little to retard the subsurface movement of NO_3^- in the presence of macropores. In many cases, macropores are responsible for the transport of nutrients such as NO_3^- at high concentrations (>10 mg L^{-1}) deeply into the profile (1.8 m). In any case, matrix flow is generally an insignificant transport mechanism in the presence of macropore flow.

Influence of Soil Type

No-till soils such as turf have greater infiltration rates due to a larger network of surface connected macropores. Hamilton and Waddington found that older lawns had higher infiltration rates because of more time for macropores to form. They also noted that management practice will influence infiltration rate through a series of events. Fertilization increases plant tissue production, which increases soil organic matter, which causes an increase in microbes and earthworms, which will increase infiltration. The soil infiltration rate can be reduced by suspended sediment in runoff, which clogs the pores and lowers hydraulic conductivity. However, this is normally only a problem of cultivated soils with an exposed surface layer.

Restrictive layers are horizons of low permeability, exhibiting hydraulic conductivity much lower than the horizons above. Water which enters the profile will accumulate on the restrictive layer, saturating the profile. Once saturated, soluble nutrients and pesticides are free to move with the water, which may flow laterally as shallow subsurface flow or end up as runoff should the profile saturate completely (saturation excess runoff). In general, the restrictive layer is not completely impermeable, as some water will drain through cracks, and earthworm burrows.

Furthermore, soil surface phenomenon can influence water movement as well. Soil surface sealing can be significant on cultivated soils. Raindrop energy can disturb smaller soil particles which are then redistributed into pores, effectively sealing them and reducing infiltration. Effluent and manures as well have the potential to clog pores and increase runoff production.

High maintenance turfgrass management utilizes more nutrients and pesticides per unit area than many other land uses and therefore has the potential to increase nutrient, sediment and pesticide loads in surface and ground water. However, correct management and knowledge of the site, i.e., soil and environmental factors, will greatly reduce potential contamination of our waters. Grasses also have the ability to clean waters, as has been shown in multiple studies discussed above.

Zachary Easton
Ph.D. Candidate, Cornell University

Editors Note: Zach is currently pursuing his Ph.D. with Professor Marty Petrovic investigating landscape, watershed and water quality issues.

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CUTT

Turfgrass Management Influence on Water Quality

Part 3: Leaching and Hydrology

Editor's Note: This is the third of a three part series on the current status of water quality research as it relates to turfgrass management. Part 1, Pesticides, was published in CUTT *Winter 2004, while Part 2, Nutrients, appeared in 2004 Issue 2 (Spring 2004).*

Much highly managed turf is grown on a sand-based rooting mix, which provides rapid—and in some cases excessive—drainage, preventing adequate time for chemical removal and attenuation. Nutrient and pesticide leaching is by far the largest contributor of chemicals to ground water. However, sandy profiles allow relatively unimpeded turf growth, avoiding many of the problems found in turf grown in other soil.

In sand, root growth and density are increased, allowing for an increased growth rate which increases thatch formation, and organic carbon deposition which increases microbe activity. These all increase the remediation potential of nutrients and pesticides in the soil. Yet, in some cases increased soil organic matter (OM) may actually increase NO_3^- leaching by increasing soil N mineralization. However, in general, increased OM has a positive affect on water quality, as it provides a greater buffer for contaminant capture.

As with runoff, single, catastrophic rainfall events can be responsible for much of the nutrient and pesticide loss in leachate. Lui et al. observed up to 40% total annual percolation losses due to a single precipitation event. In general, though, leaching is considered a more constant loss of water from a soil profile and represents a significant portion of total rainfall. Owens et al. calculated that in excess of 30% of precipitation was lost as sub surface flow. Leaching is the major pathway through which pesticides and nutrients are lost, especially from sand-based golf greens, which do not capture compounds effectively. Soils containing a higher portion of fine sediment are much more effective at nutrient and pesticide retention. A fine sandy loam studied by Branham at al. was very effective at removing 2,4-D from water; it was not detected in leachate.

Dilution and Mobility

Dilution is important in terms of reducing NO_3^- concentrations in leachate. Greater precipitation entering the profile will dilute soil solution N, but will also increase the speed at which it moves, reducing possible attenuation. Once past the root zone (15-30 cm) compounds tend not to be further attenuated, and can move to the ground water table relatively unimpeded.

Compound mobility in the soil is a function of both the compound and the soil. Soils high

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A Healthy Ecosystem

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