CUTT

Turfgrass Management Influence on Water Quality

Part 3: Leaching and Hydrology

A Healthy Ecosystem

As with runoff, single, catastrophic rainfall events can be responsible for much of the nutrient and pesticide loss in leachate.

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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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

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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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.

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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.

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

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