RUTGERS

New Jersey Agricultural
Experiment Station

Summary
Summit Meeting

ON THE

Role of Nutrient Management in Urban and Suburban Landscapes in Nutrient Loading of Surface and Ground Waters

MAY 13, 2010

BARNEGAT BAY
PARTNERSHIP
RESEARCH · EDUCATE · RESTORE

DEPARTMENT OF ENVIRONMENTAL PROTECTION
NEW JERSEY

RUTGERS ECOCOMPLEX . ENVIRONMENTAL RESEARCH AND EXTENSION CENTER
1200 FLORENCE-COLUMBUS ROAD . BORDENTOWN, NEW JERSEY . 08505-4200

Summary
Summit Meeting
on the
Role of Nutrient Management in Urban and Suburban Landscapes in Nutrient Loading of Surface and Ground Waters

May 13, 2010

Rutgers EcoComplex
Environmental Research and Extension Center
1200 Florence-Columbus Road
Bordentown, NJ 08505-4200

Co-Sponsors

Rutgers University, New Jersey Agricultural Experiment Station: Bradley Hillman, Ph.D., Senior Associate Director
Barnegat Bay Partnership: Stanton Hales, Ph.D., Director
Rutgers University, New Jersey Water Resources Research Institute: Christopher Obropta, Ph.D., Director
Rutgers University, Center for Turfgrass Science: Bruce Clarke, Ph.D., Director
New Jersey Department of Environmental Protection: Kerry Kirk Pflugh, Manager, Public Participation and Stakeholder Involvement, Office of Constituent Service

Topics and Speakers

Scale and Scope of Eutrophication in NJ	Robert Nicholson, USGS
Sources and Fate of Nitrogen in Coastal watersheds at Regional and Local Scales	Neil Bettez, Cary Institute
Nutrient Transport of Fertilizers from Turfed Landscapes	A. Martin Petrovic, Cornell
N Leaching from Long Term Turf Fertilization	Kevin Frank, MSU
Nitrogen Fate Related to Fall Fertilization	Karl Guillard, UConn
Soil and Fertilizer Phosphorus Fate in Landscapes	Doug Soldat, U. WI – Madison
Impact of Buffers on Nutrient Transport	John Stier, U. WI – Madison
Soil Function/Health/Quality Effects on Nutrient Transport	Henry Lin, PSU
Current BMPs for Nutrient Management in Florida Landscapes	Laurie Trenholm, U. FL
Current BMPs for Nutrient Management in New Jersey	James Murphy, Rutgers

Table of Contents

Executive Summary

Degraded water quality (symptomatic of eutrophication) is a continuing concern in New Jersey; over 70 percent of assessed waters do not attain trout or aquatic life use objectives. Eutrophication of freshwaters is typically associated with phosphorus loading while nitrogen loading is the primary concern in coastal waters.

Land development in urban and suburban areas impacts water quality in a number of ways. Clearing of forests, woodlands, and other vegetation releases nutrients (N and P previously immobilized by plants and soil organisms), which can leach into groundwater or run off into nearby surface water bodies. Land clearing also exposes soil and the nutrients contained therein to the erosive forces of water and wind, which transports these soil particles and nutrients into surface water bodies. Soil erosion during land development (construction) is considered the primary source of phosphorus loading of freshwaters. Land development also disturbs and degrades the soil within an ecosystem to the extent that more water runs offsite and the ability to support plant growth is difficult (in many cases unfeasible) without supplemental inputs of fertilizer and irrigation and/or restoration of soil function.

A survey of 16 coastal watersheds in the northeastern U.S. identified the major sources of nitrogen as: atmospheric deposition (31%), food and feed imports (25%), agricultural N_2 fixation (24%), fertilizer use on agricultural and urban landscapes (15%), and forest N_2 fixation (5%). Some of the nitrogen that is added to any landscape leaches out to nearby water bodies while the remainder is retained within the watershed. Nitrate loading of water bodies often increases in urban land areas because nitrogen inputs are greater and retention of those inputs is lower in urban lands. More research, however, is needed to fully understand these processes controlling nitrogen transport and retention within specific land types and uses. Also, it is important to recognize that current-day water quality is impacted by both present and past (timescale of years to centuries) inputs of nitrogen.

The greatest risk factors for nutrient losses from turf that have been confirmed through research include:

- fertilizing during establishment of turf areas,
- thin or sparse stands of plants (low vegetative cover),
- over fertilization,
- late season applications of nutrients,
- excessive irrigation, and
- other site factors such as soil conditions and hydrology.

The amount of total P lost from a landscape is often explained more by the volume of water runoff than the general type of landscape; a greater the volume of water transports more nutrients. Nitrate leaching losses from different types of turf are predominately driven by winter precipitation.

Research also indicates that the risk for P runoff from high maintenance lawn areas is lower due to the dense vegetative cover of high maintenance lawns, which intercepts and slows water movement and allows for greater infiltration into the soil rather than runoff. Additionally, non-nitrogen-fertilized turf allows more runoff to occur and, therefore, greater transport of phosphorus in that runoff. This has serious implications for non-fertilized buffers that otherwise will continue to be maintained as turf (more below).

As a result, the major emphasis in current best management practices (BMP) recommendations for phosphorus management is to limit phosphorus fertilization of turf to the period of March through September (avoiding winter precipitation) and only when:

(i) Soil test results indicates phosphorus is needed, and/or
(ii) Turf is being repaired (seeded or sodded).

The major emphasis of current best management practices (BMP) recommendations for the management of nitrogen include:

(i) Restricting the application of N fertilizer to turf during the period of March through November (avoiding winter precipitation);
(ii) Using the appropriate annual rate of nitrogen fertilization based on the need and function/use of the turf rather than an arbitrary value;
(iii) Using low to moderate per-application rates of nitrogen rather than high per-application rates; and
(iv) Irrigating turf with modern water conservation strategies since excess irrigation can increase the risk of leaching and runoff.

Slow release fertilizers are generally considered a secondary tactic within BMP recommendations to reduce the risk of high per-application rates of nitrogen fertilizers. Nitrogen rates above 0.7 to 0.75 pound per 1,000 square feet are typically considered high. Because the uptake of nitrogen by plants is highly efficient at low to moderate per-application rates of nitrogen (subsequently leaching risk is low), BMP recommendations to use slow release nitrogen fertilizer are typically made when there is the need/desire to make fewer applications of nitrogen at high rates. Nitrogen rates below 0.5 pound per 1,000 square feet are typically considered low and the rates between 0.5 and 0.75 are considered moderate.

Currently, there are no studies that indicate there is an “ideal” amount (percentage) of slow release nitrogen regarding the ability to reduce nitrate leaching risk as well as produce healthy plant growth. There is no proven source/form (slow release, organic, synthetic, water soluble, etc.) of nitrogen fertilizer that scientists can confidently predict will prevent nitrogen leaching losses over the perspective of long term fertilizer use. Thus, scientists studying water quality impacts of turf fertilization practices are concerned that long term use of relatively large amounts of slow release nitrogen for turf fertilization will only delay leaching rather than prevent it. Slow-release-nitrogen is generally not used or recommended until the per-application rate of nitrogen exceeds the range of 0.5 to 0.75 pound per 1,000 square feet.

Annual nitrogen rates above 4 pounds per 1,000 square feet are typically considered high; however, this may not be high for some situations. For example, intensively used turfs (sports and golf) will often require 4 or more pounds of nitrogen fertility annually to tolerate and recover from damage in intensively used areas. Furthermore, turf being grown on poorly constructed soils will often need greater nitrogen inputs to correct the limited nutrient supplying capacity of those soils. As a landscape matures (decade or more), the annual need for nitrogen input often declines. More research is needed to gain understanding of annual nitrogen input across different soil types.

Buffers are recommended to avoid direct application of fertilizer to water bodies. Research does support the concept of non-phosphorus fertilized along water bodies to reduce phosphorus runoff; however, elimination of nitrogen fertilization (as well as phosphorus) has resulted in greater runoff losses of phosphorus within 2 years of having stopped all (N and P) fertilization from traditional lawns with Kentucky bluegrass. Maintaining a dense vegetative cover within buffers will be critical to the function of these buffers; research data suggests that a loss of vegetative cover (due to elimination of all fertilization) can result in greater nutrient (phosphorus) loading of adjacent water bodies. Recommendations for appropriate buffer size are not clear because of the numerous factors affecting the performance of buffer; more research is needed to better understand the design and subsequent effects of buffers.

Landscapes should be constructed and managed to improve the function (e.g., infiltration capacity, water storage, etc.) of soil and maintain plant density (soil cover) to reduce the volume of runoff and subsequently nutrient loads. High density plant cover (such turfgrass) is highly effective at slowing runoff and enhancing water infiltration and storage in the soil. Restoring soil function in developed landscapes is a highly effective water conservation practice since an increased capacity to store rainfall in soil will reduce the need (frequency and amount) for irrigation to sustain growth of landscape plants.

This effect of soil restoration to reduce the demand for irrigation has an additional positive impact on water quality. Routine irrigation increases the risk for nitrogen leaching because more frequent irrigation can maintain relatively high soil water conditions. Leaching risk is greatest when soil water content is high. Thus, nutrient management BMPs stress the importance of proper turf irrigation using technologies (for example, “smart” sensors for soil water content and evapotranspiration) and strategies that promote water conservation. Research is needed to assess proper irrigation management such as strategies that encourage some drying of the soil to avoid increasing the risk of nitrogen leaching.

The specific research needed to improve our ability to managed nutrients in urban and suburban landscapes and reduce nutrient loading of surface- and groundwaters includes:

(i) Development of low input turfgrasses;
(ii) Evaluation of changes in the properties (function) of urban soils including organic matter content and water infiltration and retention for impacts on water quality and conservation;
(iii) Determination of the effect of buffer size and type within urban landscapes to protect water quality;
(iv) More discriminative data on N and P fertilization rate effects on water quality as well as turf response;
(v) Optimization of fall fertilization practices including proper fertilizer sources/forms, timings, and rates regarding water quality; and
(vi) Development of a more objective method/test to determine when and how much nitrogen fertilizer should be applied.

Background

Degraded water quality is a continuing concern in New Jersey, where over 70 percent of assessed waters do not attain trout or aquatic life use objectives, based on evaluation of numeric water-quality criteria and biological indicators. Problems associated with most of these criteria and indicators are symptomatic of eutrophication, a condition afflicting both freshwater bodies and estuaries in New Jersey.

The term, eutrophication, refers to an enhanced or excessive rate of biological production within an ecosystem, usually due to an increase in nutrient inputs (e.g., nitrogen and phosphorus). The subsequent negative environmental effects include anoxia (depletion of oxygen) and severe reductions in water quality, fish, and other animal populations; some species may increase in population, which negatively affects other species in the ecosystem. Phosphorus is frequently the nutrient of greatest concern for freshwater bodies whereas nitrogen is typically the primary nutrient that limits biological productivity in coastal waters. Other nutrients can have secondary eutrophic effects as inputs of primary limiting nutrients are increased, as demonstrated by Seitzinger et al (2001) using microcosm experiments representing conditions in Barnegat Bay.

Perspective at the Watershed Scale

Within NJ, there are 21 impaired freshwater water bodies with proposed total maximum daily loads (TMDLs) for phosphorus while total phosphorus TMDLs have already been approved for 55 other freshwater bodies (NJDEP, 2010). Soil erosion during land development (construction) is a primary source of phosphorus loading (Johnson and Juengst, 1997).

The National Oceanic and Atmospheric Administration updated the National Estuarine Eutrophication Assessment in 2004, which includes assessments of New Jersey estuaries (Bricker et al, 2007). The eutrophic conditions in the Hudson River/Raritan Bay and Delaware Bay have been classified as moderate (symptoms generally occur less regularly and/or over medium area); whereas, eutrophic conditions in the Barnegat Bay and New Jersey Inland Bays were classified as high (symptoms generally occur periodically or persistently and/or over extensive area). There has been no change in the symptoms of the Hudson River/Raritan Bay, Delaware Bay, and New Jersey Inland Bays since the 1999 assessment. However, there has been a worsening of the trends in Barnegat Bay since the 1999 assessment. Eutrophic conditions in Barnegat Bay are characterized by high chlorophyll-a, low dissolved oxygen, algal blooms and epiphytic algal growth, declining seagrass, and highly reduced fisheries.

Although there are natural sources of nitrogen (lightning and nitrogen fixing organisms), the major sources of nitrogen are anthropogenic (fertilizer and fossil fuel combustion). The contribution of each of these sources to coastal systems varies with respect to the land use in each watershed. A recent assessment indicated that the major sources of nitrogen to 16 coastal watersheds in the northeastern U.S. were: atmospheric deposition (31%), food and feed imports (25%), agricultural N_2 fixation (24%), fertilizer use (15%), and forest N_2 fixation (5%) (Boyer et al., 2002). However, if the effect of fertilizer use, fixation in croplands, and animal feed imports are combined the largest overall source is agriculture. As points of reference, the nitrogen in fertilizer sold in Ocean County for both agricultural and urban uses was 482,000 pounds in 2008 (C. Wible, written commun., 2010). Atmospheric deposition of nitrogen to the land area in the Barnegat Bay watershed (660 square miles) was estimated to be 1.8 million pounds (Weiben and Baker, 2009).

A recent assessment indicated that the major sources of nitrogen to 16 coastal watersheds in the northeastern U.S. were: atmospheric deposition (31%), food and feed imports (25%), agricultural N2 fixation (24%), fertilizer use (15%), and forest N2 fixation (5%) (Boyer et al., 2002). However, if the effect of fertilizer use, fixation in croplands, and animal feed imports are combined the largest overall source is agriculture. The ratio of fertilizer inputs to atmospheric inputs in these watersheds ranged from a 0.05 - 1.33, and the ratio of area-weighted average inputs was 0.49. Watershed retention of nitrogen from different sources varies widely, and as a result, the actual delivery of nitrogen as loads to coastal water bodies from various sources will likewise vary widely. The net result is that the delivered nitrogen load to water bodies is typically much less than the sum of the inputs. The percentage of nitrogen from all sources that was exported in stream flow from the 16 coastal watersheds ranged from 11 - 40% (from Boyer et al, 2002). As points of reference, the nitrogen in fertilizer sold in Ocean County for both agricultural and urban uses was 482,000 pounds in 2008 (C. Wible, written commun., 2010). Atmospheric deposition of nitrogen to the land area in the Barnegat Bay watershed (660 square miles) was estimated to be 1.8 million pounds (Weiben and Baker, 2009). Therefore, assuming that fertilizer sales in Ocean County represents a reasonable approximation of fertilizer inputs to the Barnegat Bay watershed, the ratio of fertilizer inputs to atmospheric inputs in the Barnegat Bay watershed is about 0.27, which is lower than the average for the 16 coastal watersheds.

Land use also has an impact both on the amount of nitrogen that is added to a watershed and the amount that is retained within the watershed. The total nitrogen input into a watershed will typically be much greater on croplands and urban landscapes than forestlands (Castro et al. 2003). Although some of the nitrogen that is added to the landscape leaches out to nearby water bodies, some is retained within the watershed, with the amount of retention related to land use. Forested land has been reported to retain most (85 to 95%) of nitrogen inputs (which has the lowest input, mostly atmospheric deposition) while croplands retain less than forests and urban lands retain less than croplands (Castro et al., 2003). However, a recent study, part of ongoing long-term ecological studies of the Baltimore metropolitan area, found that residential landscapes dominated by lawns had the same amount of nitrogen sequestered in these soils as was applied as fertilizer (Raciti, 2010). Thus, more study is needed to clarify the role of the specific land types within urban landscapes regarding nutrient retention and loading of water bodies.

At the watershed scale it is evident that nitrate loading of water bodies often increases as urban land use increases (greater nitrogen input and less retained), as demonstrated in the Barnegat Bay watershed by Hunchak-Kariouk and Nicholson (2001). A recent estimate of the load of nitrogen delivered to Barnegat Bay is 650,000 kg-N per year (1.4 million pounds per year). Delivery pathways include direct atmospheric deposition (22%), groundwater discharge directly into the bay (12%), and surface water discharge, which includes nitrogen in stormwater and in groundwater discharge as baseflow in streams (66%) (Weiben and Baker, 2009). A study of three streams in the watershed indicated that baseflow (groundwater) in streams contributed more to nitrogen loading in two of the three streams; whereas stormwater flow was much more important in the third stream. Thus, groundwater is an important transport pathway whether it occurs directly into the bay or indirectly through stream baseflow into the bay (Baker and Hunchak-Kariouk, 2006). An evaluation of groundwater sample results indicated that the nitrogen concentration in a substantial fraction of the shallow groundwater in Ocean County is above levels of ecological concern (Wieben, 2007). Also important to recognize is the time scale for groundwater transport, which can range from years to centuries depending on the specific hydrologic conditions of the watershed. Additionally, stormwater flow can not be ignored as transport pathway. More study is needed to fully understand these processes controlling nitrogen transport but it is likely that specific land types and uses, both present and past, are important. Isotope analysis of surface-water and groundwater samples may be helpful in future studies to determine the major sources of nitrogen loading by identifying isotopic signatures of precipitation, fertilizer, soil nitrogen, and manure and septic waste.

A statewide study indicated that source area factors that can explain variability in nitrate concentrations in groundwater are, in order of importance: agricultural land use, urban land use, and septic tank density. Source area factors that can explain variability in nitrate concentrations in surface water are, in order of relative importance, sewage treatment plant density, agricultural land use, urban land use, and septic tank density (Baker and Vowinkel, in press).

Impact of Landscape Development

Land development impacts water quality in a number of ways. Clearing of forests, woodlands, and other vegetation releases previously immobilized nutrients (N and P), which can then leach into groundwater or run offsite into nearby surface water bodies. Land clearing also exposes soil and the nutrients contained therein to the erosive forces of water and wind, which transports these nutrients and soil particles into surface water bodies. Manipulation of land forms to accommodate transportation and commercial and residential buildings alters a site's hydrology such that more stormwater runoff is generated (Burton and Pitt, 2002; Carter, 2009). This increase in runoff subsequently increases the amount of nutrients and soil that can be carried along with the runoff to nearby water bodies (Holman-Dodds et al., 2003).

Soil provides many functions within ecosystems including the capture and storage of nutrients and rain, which are then used by plants and other flora and fauna within the ecosystem. Land development disturbs the soil within an ecosystem to the extent that more water runs off site and the ability to support plant growth is difficult (in many cases unfeasible) without supplemental inputs of fertilizer and irrigation. Moreover, the expertise of citizens to use these inputs efficiently within urban landscapes is limited.

Efforts to maintain and improve water infiltration into soil as well as to stabilize the soil with vegetative cover (e.g., turf) reduce runoff and nutrient loadings as well as contribute to sustaining groundwater supplies. Improving soil function within developed (urban) landscapes would reduce the need for supplemental fertilizer and irrigation inputs. Over the long term, practices that improve soil structure, remediate compaction, sustain adequate soil organic matter content, and prevent soil erosion are perhaps the cheapest and most effective strategies for improving water quality and conserving water supplies.

Eutrophication of coastal waters is an increasingly greater challenge within watersheds that have or are undergoing conversion to crop and/or urban land uses. The risk of eutrophication intensifies in urban lands because nutrient inputs not only increase but these inputs are less likely to be retained within an urbanized watershed. The extensive conversion of land area within New Jersey to urban uses makes eutrophication of coastal waters a statewide concern.

Assessment of Turfgrass Systems

Landscape Type and Nutrient Losses

Nutrient inputs into turfgrass systems include fertilizer but also plant debris (tree leaves, pollen, etc.), compost, rain and irrigation water, dust, and pet and wildlife waste. Nitrogen losses from turfgrass into water bodies may occur through leaching into groundwater and, to a lesser extent, through surface water runoff and soil erosion. Conversely, phosphorus losses into water primarily occur with soil erosion and water runoff; leaching is usually a minor transport pathway.

It needs to be emphasized that one critical function of perennial vegetative cover in the environment is the capture and retain soil and the nutrients it contains, which protects water quality. Studies have clearly demonstrated that annual sediment and phosphorus loads in urban areas can vary dramatically depending on the land use (Chesters et al., 1979; Madison et al., 1979; Novotny and Chesters, 1981). For example, the Wisconsin Department of Natural Resources (DNR) estimates that sediment loads from construction sites average 60,000 lbs (30 tons) per acre, which is more than any other land use (Johnson Juengst, 1997). Sediment loads of between 800 and 1,000 lbs per acre were estimated for freeways, industrial and commercial sites. In contrast, the DNR estimated 400 and 200 lbs per acre for multi-family dwellings and small residential lots, respectively, while large lot residential and parks were less than 50 lbs per acre (Johnson and Juengst, 1997). Within urban watersheds, 50 to 70% of phosphorus loading has been attributed to sediment losses in runoff.

This function of nutrient retention is further exemplified in data from the Baltimore Ecosystem Study, which reported that residential land, when converted from agricultural land, can serve as sink for nitrogen, accumulating nitrogen at approximately 8.3 $g/m^2/yr$ (1.7 $lbs/1000\text{-}ft^2/yr$) up to 44 years (Raciti, S.M., Ph.D. Thesis 2010, Cornell Univ.). Porter et al. (1980) reported that the amount of total nitrogen accumulating in turf increases with age, which approaches a maximum in about four decades.

Despite this ability to accumulate nitrogen, losses of N from residential lands in the Baltimore Ecosystem Study was reported as 1.4 $g/m^2/yr$ (0.3 $lbs/1000\text{-}ft^2/yr$) compared to 0.4 $g/m^2/yr$ (0.09 $lbs/1000\text{-}ft^2/yr$) for forested land (Groffman et al., 2009). Thus, a better understanding of nutrient inputs and the factors associated with retention, transport and loading of waterways is needed to improve nutrient management within urban landscapes.

Runoff Volume (“Follow the Water”)

The amount of total P lost from a landscape is often explained more by the volume of water runoff than the general type of landscape. On sites with a high potential for runoff, high maintenance lawns lost the same amount of total P in runoff compared to unfertilized low maintenance lawns and wooded sites but higher amounts of soluble P (Easton and Petrovic, 2008). However, on sites with moderate to low potential for runoff, high maintenance lawns had about half the amount of total P runoff compared to unfertilized low maintenance lawns and wooded sites. The lower risk for P runoff from high maintenance lawn area is thought to be a result of the dense vegetative cover, which intercepts and slows water movement and allows for greater infiltration into the soil rather than runoff.

Lawn conditions that result in the greatest amount of runoff include a newly seeded (establishing) lawn and established lawns with low plant density (for example, largely comprised of annual vegetation/weeds such as crabgrass) and wet soil (well irrigated). Doubling the amount of shoots in a lawn (32 to 64 per inch^2) has reduced runoff volume by two-thirds. Conversely, runoff problems have increased within 2 years after fertilizer nutrients (both N and P) are withheld from a Kentucky bluegrass lawn (Slavens and Petrovic, 2010).

Studies of phosphorus runoff in the upper mid-west indicate that the majority (80 to 87%) of phosphorus loading from turfgrass occurs during frozen conditions (no infiltration) in the winter and/or spring during rain/snow melt (Stienke et al., 2007; Kussow, 2008; Bierman et al., 2010). However, in central NY, the P runoff losses during the winter month was only 8% (for particulate P) to 11% (for dissolved and total P) of the total P lost in runoff from a suburban watershed (Easton and Petrovic, 2008).

Turf Management Factors

Phosphorus Fertilization and Loading

A comprehensive review of studies evaluating phosphorus losses from turfgrass (Soldat and Petrovic, 2007) found that under a worst-case scenario (fertilizer applied then rain simulated), phosphorus in runoff was in the range of <1 to 18% of phosphorus applied or 0.004 to 0.31 g/m^2. Under conditions of natural rain, plot-scale data indicates annual phosphorus loads of 0.01 to 0.2 g/m^2 from turfgrass. Quantifying land use at the watershed scale and measuring water quality and quantity indicates phosphorus losses tend to be less than 0.05 g/m^2 (Soldat and Petrovic, 2007).

Research has demonstrated that non-nitrogen fertilized turf allows more runoff to occur and, therefore, greater transport of phosphorus in that runoff; this has implications regarding the management of buffers discussed below. The greater amount of runoff occurs under non-fertilized conditions because there is less vegetation at the soil surface, which intercepts and slows the movement of water and provides more time for water to infiltrate into the soil rather than run offsite (Soldat and Petrovic, 2007). Longer term, grasses are also widely recognized for the ability to improve a soil's ability to infiltration; furthermore, dense, perennial broadleaf weedy lawns also have been shown to have low runoff and high infiltration (Slavens, M. Ph.D. dissertations, Cornell University, 2010).

Nitrogen Rate

Detailed studies of the impact of nitrogen fertilizer rate on water quality is limited but the available data indicates that nitrogen leaching potential does increase as the per-application and annual amount of nitrogen fertilizer applied increases. Generally, more leaching has occurred when rates greater than 4.9 g/m^2 (1 lb N/1,000 sq.ft.) were applied. Results from an eleven year nitrogen leaching study on Kentucky bluegrass turf indicate that nitrate leaching was much greater when the turf was fertilized at 24.4 g/m^2/yr (5 lbs/1000-ft^2/yr) than 9.8 g/m^2/yr (2 lbs/1000-ft^2/yr) (Frank et al., 2006). Moreover, nitrate leaching was dramatically reduced within 2 years when the high rate of nitrogen fertilization was reduced from 24.4 to

19.5 g/m^2/yr (5 to 4 lbs/1000-ft^2/yr) (Frank, 2008; 2009). Thus, it is important to emphasize in best management practices (BMPs) recommendations that the annual rate of nitrogen fertilization be appropriate to the needs of the turf rather than an arbitrary value.

Timing of Fertilization

Studies of cool-season turf in temperate climates indicate that late fall through winter is the time of year with the greatest risk for nitrate leaching from cool season turf (Frank, 2008; 2009; Frank et al., 2006; Mangiafco and Guillard, 2006; Petrovic, 2004b). Nitrate leaching losses from different types of turf are predominately driven by winter precipitation (Slavens and Petrovic, 2010). The reason – plants uptake nitrate-nitrogen in transpiration water, so water has to be moving into the plant (transpiration) for nitrate uptake to occur. And because the transpiration rate is very low during the winter, nitrate uptake into plants is slow. Consequently, nitrate-N can be resident in the soil for a longer period of time when soils are typically wet and precipitation exceeds transpiration, resulting in more leaching of nitrate. This pattern of leaching has been observed repeatedly during the eleven year leaching study in Michigan where Kentucky bluegrass received relatively high rates of nitrogen fertilizer [24.4 g/m^2/yr (5 lbs/1000-ft^2/yr)]. A trial in Connecticut indicated the risk for nitrate leaching increases as the last date of fertilization is performed later in the year; December fertilization had the greatest leaching potential much less than in September (Mangiafco et al., 2006). Guillard and Kopp (2006) found that slow release fertilizers could reduce this risk of late-season fertilization; however, this work was not designed to identify the minimum amount of slow release nitrogen needed to reduce the leaching risk with late season applications.

Fertilizer Source/Form

Fertilizers can be classified as quickly (water soluble) or slowly available (slow release). Plants rapidly uptake water soluble nutrients when supplied at low to moderate rates; this essentially immobilizes these nutrients preventing runoff and leaching losses. Thus, frequent, low rate, applications of water soluble fertilizers are highly efficient and an excellent BMP. Alternatively, fertilizers are applied at higher rates to lower the costs of time and labor.

The source/form of nitrogen fertilizer can impact leaching losses, particularly at higher application rates and where large amounts of water are applied either as irrigation or rain. Water soluble nitrogen fertilizers, especially nitrate fertilizers such as calcium nitrate, have a greater leaching potential than other sources of nitrogen (fortunately, nitrate fertilizer is not frequently used as turf fertilizer). Thus, it is important not to apply high rates of soluble nitrogen sources in advance of anticipated heavy precipitation to reduce the leaching risk. Slow release nitrogen fertilizer is often recommended as a tactic to minimize this risk.

Under drier conditions, however, slow release fertilizers will have little to no impact on nitrogen leaching since there is not enough water flow to produce leaching before the applied nitrogen is immobilized by plants, other flora, and fauna. In one study, conducted over a wide range (thus long term implications) of rainfall conditions (drier, normal and much wetter than normal) the form of nitrogen (except for calcium nitrate) had little to do with the amount of leaching (Petrovic, 2004). Unfortunately, there have not been any long term (more than 3 years) studies that evaluated the effect of multiple forms of nitrogen fertilizer such as water soluble, slow release, and organic nitrogen on nitrogen leaching. As result, scientists studying nitrogen fate and transport in turfgrass systems have concerns, albeit unsubstantiated, about widespread and long term use of slow release fertilizers for turf. There are two reasons for concern, the first involves the potential for users to apply greater total amounts of N to achieve desired growth response and turf function since slow release nitrogen fertilizer (applied at the same rates as quick release nitrogen fertilizer) will substantially delay growth response of plants. Over the long term, a persistent use of slow release fertilizers at rates higher than would be needed/used for quick release fertilizers could eventually result in greater nitrogen leaching. Second, when studying the amount of applied nitrogen that is recovered in the clippings, the more water soluble the fertilizer source the greater the amount of nitrogen recovered in the clippings, up to twice as much (Hummel and Waddington, 1981).

Thus, from the perspective of long term fertilizer use, there is not a scientifically proven source (slow release, organic, synthetic, water soluble, etc.) of nitrogen fertilizer that scientists can confidently predict will prevent nitrogen leaching losses. Based on observations at the watershed scale, a reduction in total nitrogen input results in a greater retention (lower losses) of nitrogen within a landscape. Thus, the current BMP recommendations emphasize appropriate limits for total (annual) application rate as well as the per-application rate of water soluble nitrogen to minimize the risk for nitrogen leaching.

BMP recommendations to use slow release nitrogen fertilizer “kick in” when there is the need/desire to make fewer applications at higher rates. As mentioned earlier, low application rates of water soluble nitrogen fertilizer is a highly effective BMP. The question becomes – what constitutes a “high” rate? University recommendations typically begin suggesting the use of slow release fertilizers at nitrogen application rates within the range of 0.5 to 1 lb/1000-ft^2. The reason for this range, rather than a specific singular rate, is due to the highly variable plant response that can occur within this range. Factors affecting plant response to nitrogen include soil type, plant species, soil organic matter and water content, and temperature. Moreover, there are many types of slow release nitrogen, which also impacts what proportion of slow release nitrogen can be used/included in a plant fertilizer.

The following URLs are provided as examples of current University recommendations for turf fertilization. http://www.hgic.umd.edu/_media/documents/hg103_002.pdf
http://cropsoil.psu.edu/turf/extension/factsheets/fertilization
http://njaes.rutgers.edu/pubs/publication.asp?pid=E327
http://edis.ifas.ufl.edu/ep236

Comparison of synthetic and organic phosphorus fertilizers on turf have not demonstrated a difference in phosphorus runoff losses. In fact, the application of either source to turf compared to no fertilizer has reduced phosphorus losses in runoff for reasons discussed above.

Irrigation

The amount of irrigation water applied to turf can influence runoff and leaching losses of nitrogen. The amount of ammonium-N leached and nitrate-N in runoff from turf can increase as irrigation quantity increases (Slavens and Petrovic, 2010). Over irrigation can greatly increase the extent of nitrate-N leaching losses, especially when high rates of N are applied (5 lbs N/1000 sq.ft./yr) compared to evapotranspiration rate based irrigation (Morton, et al., 1988).

Buffers

Research on buffers has received much more attention in agricultural landscapes than urban landscapes (Daniels & Gilliam, 1996; Clausen et al., 2000; Lee et al., 2000; Dosskey et al., 2002; Lowrance et al., 2002). Urban land uses are complicated by the presence of impervious surfaces contributing to runoff in addition to that from turf areas Burton and Pitt, 2003; Carter, 2009; Holman-Dodds et al., 2003; Jackson, 2003).

As mentioned previously, research does support the concept of non-phosphorus fertilized along water bodies to reduce phosphorus runoff; however, as also mentioned above, elimination of nitrogen fertilization (as well as phosphorus) has resulted in greater runoff losses of phosphorus within 2 years of having stopped all (N and P) fertilization from traditional lawns with Kentucky bluegrass. The reason – a decline in vegetative cover (resulting from the zero nitrogen fertilization) results in less interception of water and greater runoff, which transport more phosphorus.

Research studies indicate that increasing the height of vegetation in a buffer can reduce runoff. Raising the mowing height increases the amount of vegetation, which intercepts and slows water movement resulting in more infiltration of water and less runoff.

Research comparing vegetation types (fescue vs. prairie plants) and ratios of buffer length to turf length as well as no buffer indicated there were no benefits to these buffers in the amount of water runoff or total phosphorus lost. In fact, more nitrate leaching occurred from plot with buffers within the first year due to the disturbance of soil during establishment of the fescue and prairie buffer vegetation.

Prairie and turf have been compared as buffer vegetation for stormwater control from impervious surfaces. Buffer strips of mowed and fertilized Kentucky bluegrass turf had similar levels of runoff and sediment and nutrient loading compared with forb-dominated prairie vegetation two and three 3 years after seeding. Thus, low-maintenance landscapes can be a source of P in urban environments due to natural the P uptake by plants and the subsequent leaching from vegetation. Buffer strips with a 4:1 pervious/impervious surface ratio reduced runoff volume, sediment, phosphorus, and nitrogen loss compared to 1:1 buffer strips but only during non-frozen conditions.

Rain gardens are recommended as buffers to ameliorate rooftop runoff. A study comparing rain gardens vegetated with either Kentucky bluegrass turf or a mixture of plants typically recommended for rain gardens and constructed either with or without a berm concluded that runoff volume is critical for managing phosphorus pollution. In this study, the presence of a berm was the critical feature needed in a rain garden to reduce stormwater runoff. Very often, any effect of vegetation type was negated by the presence of the berm in this study. In the absence of a berm, turf was sometime better at reducing runoff than the mixed species vegetation. Vegetation type and berm construction had some influence on total suspended solids in runoff water but there was no difference in the mean total phosphorus concentration in runoff. Very few samples in this study met the criteria of 0.1 mg/L of phosphorus for streams/rivers or the 0.05 mg/L of phosphorus for lakes/reservoirs.

Research Priorities

While information has been gained through research, there is still a need to further our understanding of nutrient inputs and the factors associated with retention, transport and loading of waterways. Increased knowledge of these factors will impact our ability to better manage nutrients within urban landscapes and improve water quality.

Specific research needs include: i) the development of low input turfgrasses; ii) the effect of buffer size and type within urban landscapes to protect water quality; iii) more discriminative data on N and P fertilization rate effects on water quality as well as turf response; iii) the effect of late fall fertilization practices including fertilizer sources/forms, timings, and rates on water quality; iv) the development of a more objective method to determine when and how much nitrogen fertilizer should be applied; and v) the evaluation of changes in soil properties including organic matter content and water infiltration and retention for impacts on water quality.

Recommendations for the amount (application rate) and timing of nitrogen fertilization could probably be improved by the development of reliable soil and/or plant tissue tests. More specifically, research is needed to improve our ability to properly interpret the results of any soil or plant tissue nitrogen tests. Without such data our current ability to enhance nitrogen fertilization practices based on recommendations, especially by inexperienced users of fertilizer, is limited. Development of cost-effective techniques and recommendations that improve soil structure, remediate compaction, and improve soil organic matter content are perhaps the most effective strategies for improving water quality and conserving water supplies.

Risk Summary and General Recommendations

The greatest risk factors for nutrient losses from turf that have been confirmed through research include:

- fertilizing during establishment of turf areas,
- thin stands of plants (low vegetative cover),
- over fertilization,
- late season applications of nutrients,
- over irrigation, and
- other site factors such as soil conditions and hydrology.

Landscapes should be managed to improve the function (e.g., infiltration capacity) of soil and maintain plant density (soil cover) to reduce the volume of runoff and subsequently nutrient loads. High density plant cover (such turfgrass) is a highly effective at slowing runoff and enhancing water infiltration and storage in the soil.

Fertilization rates for turfgrass and other plants should to be based on appropriate factors with a strong emphasis on using the lowest amount of nutrients necessary to achieve the function of the turf for a given site. Maintenance of soil cover, as mentioned above, needs to be a primary consideration on landscapes receiving low nutrient inputs, otherwise greater nutrient loading, especially phosphorus, in waterways is probable.

Improvement of soil function in urban landscape through enhancement of soil structure and organic matter content would also reduce the amount of fertilizer inputs needed to maintain landscape plantings.

Late autumn fertilization increases the potential for nitrate leaching. Although trial data is limited, recent studies indicate it would be wise to end fertilizer applications by mid-November or when plant water uptake is small.

Whenever water moves offsite (runoff or leaching) there is greater risk of nutrient transport. Therefore, irrigation practices need to be conservative. It is important to maintain relatively dry to moist soil conditions on sites that are irrigated because the soil will be more capable of capturing rainfall (via infiltration) when it is drier rather than wetter as well as limiting the amount of runoff and leaching.

Urban runoff models need to account for winter runoff when determining potential for nutrient loading especially in areas subject to freezing and regular snow cover. Urban designs should prevent runoff during winter and early spring conditions from directly entering surface waters to reduce nutrient and sediment loading.

References and Additional Readings

Baker, R.J. and Hunchak-Kariouk, K, 2006. Relations of water quality to streamflow, season, and land use for four tributaries to the Toms River, Ocean County, New Jersey, 1994-99: U.S. Geological Survey Scientific Investigations Report 2005-5274, 72 p.

Baker, R.J., and Vowinkel, E.F., in press. Vulnerability of groundwater and surface water to contamination by nitrate in New Jersey: U.S Geological Survey Scientific Investigations Report xxxx-xxxx.

Bennett, E.M., S.R. Carpenter, and M.K. Clayton. 2004. Soil phosphorus variability: Scale-dependence in an urbanizing agricultural landscape: Landscape Ecol. 20:389-400.

Bierman, P.M., B.P. Horgan, C.J. Rosen, and A.B. Hollman. 2010. Phosphorus runoff from turfgrass as affected by phosphorus fertilization and clipping management. J. Environ. Qual. 39:282-292.

Bowman, D.C. 1993. The effects of nitrogen deficiency on tissue $N0_3$, reduced N, soluble carbohydrates, and uptake of NO_3 and NH_4 by perennial ryegrass. International Turfgrass Society Research Journal. 7:664-672.

Boyer, E., W., C. Goodale, L., N. Jaworski, A., and R. Howarth, W. 2002. Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern U.S.A. Biogeochemistry. **58**:137-169.

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner, 2007. Effects of Nutrient

Burton, G.A. Jr., and R.E. Pitt. 2002. Stormwater effects handbook. CRC Press, Boca Raton, FL.

Chesters, G., J. Konrad, and G. Simsiman. 1979. Menomonee River Pilot Watershed Study-Summary and Recommendations, EPA-905/4-79-029. U.S. Environmental Protection Agency, Chicago, IL.

Enrichment In the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. 328 pp.

Carter, T., 2009. Developing conservation subdivisions: Ecological constraints, regulatory barriers, and market incentives. Landscape and Urban Planning 92:117-124

Castro, M., C. T. Driscoll, T. E. Jordan, W. G. Reay, and W. R. Boynton. 2003. Sources of Nitrogen to Estuaries in the United States. Estuaries 26:803-814.

Clausen, J.C., K. Guillard, C.M. Sigmund, and K.M. Dors. 2000. Water quality changes from riparian buffer restoration in Connecticut. J. Environ. Qual. 29:1751-1761.

Corsi, S.R. D.J. Graczyk, D.W. Owens, and R..T. Bannerman. 2007. Unit-area loads of suspended sediment, suspended solids, and total phosphorus from small watersheds in Wisconsin. USGS Factsheet FS-195-97: Washington, D.C.

Dosskey, M.G., M.J. Helmers, D.E. Eisenhauer, T.G. Franti, and K.D. Hoagland. 2002. Assessment of concentrated flow through riparian buffers. J. Soil Water Conserv. 57:336-343.

Daniels, R.B., and J.W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. Soil Sci. Soc. Am. J. 60:246-251.

Easton, Z. M. and A.M. Petrovic. 2008. Determining Phosphorus Loading Rates Based on Land Use in an Urban Watershed. *In* M. Nett, M.J. Carroll, B.H. Horgan, and A. M. Petrovic (eds). The Fate of Nutrients and Pesticides in the Urban Environments. Am. Chem. Soc., Symp. Series 997, Oxford Univ. Press.

Easton, Z.M. 2006. Landscape impact on suburban runoff: Determining nutrient loading rates based on land use. Ph.D. Thesis: Cornell University: Ithaca, NY.

Frank, K.W. 2009. Long-term nutrient fate. 2009 Turfgrass and Environmental Research Summary. p. 42.

Frank, K.W. 2008. Nitrogen and phosphorus fate in a 10+ year old Kentucky bluegrass turf. 2008 Turfgrass and Environmental Research Summary. p. 57.

Frank, K.W., K.M. O'Reilly, J.R. Crum, R.N. Calhoun. 2006. The fate of nitrogen applied to a mature Kentucky bluegrass turf. Crop Science. 46:209-215.

Guillard, K., and K.L. Kopp. 2004. Nitrogen fertilizer form and associated nitrate leaching from cool-season lawn turf. J. Environ. Qual. 33:1822–1827.

Hamel, S. C., and J. R. Heckman. 2006. Predicting need for phosphorus fertilizer by soil testing during seeding of cool season grasses. HortScience. 41:1690-1697.

Holman-Dodds, J.K., A. A. Bradley, and K.W. Potter. 2003. Evaluation of hydrologic benefits of infiltration based urban storm water management. J. Amer. Water Res. Assoc. 39:205-215.

Houlihan, Steven M. 2005. Soil Test Selection and Calibration for Turfgrass in Wisconsin. M.S. Thesis: University of Wisconsin-Madison: Madison, Wisconsin.

Hummel, Jr., N. W., and D. V. Waddington. 1981. Evaluation of slow-release nitrogen sources on Baron Kentucky Bluegrass. Soil Sci. Soc. Am. J. 45:966-970.

Hunchak-Kariouk, K., and Nicholson, R.S., 2001, Watershed contributions of nutrients and other nonpoint source contaminants to the Barnegat Bay-Little Egg Harbor estuary: Journal of Coastal Research, Special Issue 32, pp. 28-82.

Jackson, L.E., 2003. The relationship of urban design to human health and condition. Landscape and Urban Planning. 64:191-200.

Johnson, C.D., and D. Juengst. 1997. Polluted urban runoff - A source of concern. Publication GWQ020 University of Wisconsin-Extension: Madison, WI.

Ketterings, Q.M., J.E. Kahabka, and W.S. Reid. 2005. Trends in phosphorus fertility of New York agricultural land. J. Soil Water Conserv. 60:10-20.

Kussow, W.R. 2008. Nitrogen and soluble phosphorus losses from an upper Midwest lawn. P 1-18. *In* M. Nett et al. (eds.) The fate of turfgrass nutrients and plant protection chemicals in the urban environment. American Chemical Society. Washington D.C.

Lee, K.H., T.M. Isenhart, R.C. Schultz, and S.K. Mickelson. 2000. Multispecies riparian buffers trap sediment and nutrients during rainfall simulations. J. Environ. Qual. 29:1200-1205.

Linde, D.T., T.L. Watschke, A.R. Jarrett, and J.A. Borger. 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agron. J. 87:176-182.

Lowrance, R., S. Dabney, and R. Shultz. 2002. Improving water and soil quality with conservation buffers. J. Soil Water Conserv. 57:36A-43A.

Madison, F., J. Arts, S. Berkowitz, E. Salmon, and B. Hagman. 1979. Washington County Project. EPA 905/9-80-003, U.S. Environmental Protection Agency, Chicago, IL.

Mangiafico, S.S., and K. Guillard. 2006. Fall fertilization timing effects on nitrate leaching and turfgrass color and growth. Journal of Environmental Quality. 35:163-171.

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

Moss, J.Q., G.E. Bell, M.A. Kizer, M.E. Payton, H. Zhang, and D.L. Martin. 2005. Reducing nutrient runoff from golf course fairways using grass buffers of multiple heights. Crop Sci. 46:72-80.

Novotny, V. and G. Chesters. 1981. Handbook of Nonpoint Pollution Sources and Management. Van Norstrand Reinhold Company, New York.

Petrovic, A. M. 2004a. Impact of soil texture on nutrient fate. Acta Horticulturae. 661:93-98.

Petrovic, A.M. 2004b. Nitrogen source and timing impact on nitrate leaching from turf. Acta Horticulturae. 661: p. 427-432.

Petrovic, A. M., D. Soldat, J. Gruttadaurio, and J. Barlow. 2005. Turfgrass growth and quality related to soil and tissue nutrient content. Int. Turfgrass Soc. Res. J. 10(2):989-997.

Seitzinger, S.P., Styles, R.M., and Pilling, I.E., 2001. Benthic macroalgal and Phytoplankton production in Barnegat Bay, New Jersey (USA): microcosm experiments and data synthesis: Journal of Coastal Research, Special Issue 32, pp. 144-162.

Slavens, M., and A.M. Petrovic. 2010. Water quality as a result of lawn cover and management intensity. 2nd European Turfgrass Society Conference Proceedings. p.205-207.

Soldat, D.J., and A.M. Petrovic. 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Sci. 48:2051-2065.

Steinke, K., J.C. Stier, W.R. Kussow, and A. Thompson. 2007. Prairie and turf buffer strips for controlling runoff from paved surfaces. J. Environ. Qual. 36:426-439.

Raciti, S.M. 2010. Ph.D. Thesis, Cornell Univ., Baltimore Long Term Urban Ecosystem Study.

Weiben, C., and Baker, R., 2009, Contributions of Nitrogen to the Barnegat Bay-Little Egg Harbor Estuary: Updated Loading Estimates , Barnegat Bay Partnership, http://www.bbep.org/studies.html

Wieben, C., 2007, Assessment of a Shallow Ground-Water-Quality Indicator. Barnegat Bay Partnership, http://www.bbep.org/studies.html

Wible, C., 2010, written communication to S. Hales, August 10, 2010.

CO-SPONSORS

Rutgers University, New Jersey Agricultural Experiment Station: Bradley Hillman, Ph.D., Senior Associate Director

Barnegat Bay Partnership: Stanton Hales, Ph.D., Director

Rutgers University, New Jersey Water Resources Research Institute: Christopher Obropta, Ph.D., Director

Rutgers University, Center for Turfgrass Science: Bruce Clarke, Ph.D., Director

New Jersey Department of Environmental Protection: Kerry Kirk Pflugh, Manager, Public Participation and Stakeholder Involvement, Office of Constituent Service